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SPLINE MISALIGNMENT GAGING SYSTEM FOR ENGINE ACCESSORY GEARBOXE--ETC(U)

NOV 75 M L VALTIERRA, R D BROWN N00156-75-C-0896

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SPLINE MISALIGNMENT GAGING SYSTEM FOR ENGINE ACCESSORY GEARBOXES AND ACCESSORIES

Prepared by
M. L. Valtierra
R.D. Brown

Procedures & Applications Report
Contract N00156-75-C-0896

To

Naval Weapons Engineering Support Activity
Washington Navy Yard
Washington, D. C. 20374

November 13, 1975

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: RS-633	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): SPLINE Misalignment Gaging System	5. TYPE OF REPORT & PERIOD COVERED: Research Sep 1974 - Nov 1975
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): M.L. Valtierra, R.D. Brown	8. CONTRACT OR GRANT NUMBER(s): N00156-75-C-0896 new
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Southwest Research Institute, 8500 Culebra Road, San Antonio, TX 78284	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Air Systems Command (AIR-340G), Washington, DC 20360	12. REPORT DATE: 13 Nov 1975
	13. NUMBER OF PAGES: 90
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Naval Air Systems Command (AIR-340G), Washington, DC 20360	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for public release; distribution unlimited.

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SPLINES
Misalignment Measurement
SPLINE Gage
Gear Box Gage

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(OVER)

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S/N 0102-LF-014-6601

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Several sets of the gearbox and accessory spline misalignment gages are required to fil all of the current AND and MS Standard gearbox and accessory pads. In this program, a popular pad size was selected for initial development. The specific gearbox spline misalignment gage was designed for use on gearbox pads with a pilot diameter of 4.125 in. and a bolt circle diameter of 5 in. (AND 20002, AND 20007, and MS 3327). The specific accessory spline misalignment gage was designed to fit the mating accessory pads with a pilot diameter of 4.122 in. (AND 10262, AND 10267, and MS 3332). The control module was designed as a general-purpose component, suitable for use with either one of the two gages for the specific pad size chosen, as well as for other gages which may be fabricated for other pad sizes in the future.

A letter to Commander, Naval Air Systems Command which describes an operational evaluation of this gage is provided at the end of this report.

9 Research / Final Rept. Sep 74 - Nov 75,

14 SwRI -RS-633

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FOREWORD

The spline misalignment gaging system described herein was designed and developed at Southwest Research Institute under Navy Contract N00156-75-C-0896. The work was performed during the period of September 12, 1974 through November 13, 1975. The work was administered by the Naval Weapons Engineering Support Activity Systems Engineering Department, Washington Navy Yard, Washington, D. C., with Mr. M. Walczak serving as the project engineer. On August 28, 1975, Mr. F. Hall replaced Mr. Walczak as the project engineer.

The authors deeply appreciate the assistance rendered by Mr. G. L. Parks, Mechanical Branch, Service Engineering Division, San Antonio Air Logistics Center, Kelly Air Force Base, Texas, in providing a gearbox and mating accessory unit for initial use in the development of the design concept.

Acknowledgment is also extended to Messrs. S. Hurst and R. Early of the Naval Air Systems Command, Washington, D. C., M. Walczak of the Washington Navy Yard, and J. Hayes of the Naval Aviation Supply, Philadelphia, Pennsylvania, in furnishing another unit for use during the latter part of the program.

Finally, the authors appreciate the interest and assistance given throughout the program by Messrs. S. Hurst of the Naval Air Systems Command and G. E. DeLong, Naval Air Systems Command, Representative Pacific. Mr. Hurst was instrumental in initiating this program. Mr. DeLong was responsible for the arrangement of an official demonstration of the gaging system held at the Naval Air Rework Facility, North Island, California, on October 22 and 23, 1975.

ABSTRACT

The objective of this program was to design and fabricate a gaging system for measuring the aircraft engine accessory gearbox-to-spline and accessory-to-spline misalignments. This gaging system comprises, in essence, a gearbox spline misalignment gage, an accessory spline misalignment gage, and a control module containing an amplifier, an indicator, and a recorder.

Several sets of the gearbox and accessory spline misalignment gages are required to fit all of the current AND and MS Standard gearbox and accessory pads. In this program, a popular pad size was selected for initial development. The specific gearbox spline misalignment gage was designed for use on gearbox pads with a pilot diameter of 4.125 in. and a bolt circle diameter of 5 in. (AND 20002, AND 20007, and MS 3327). The specific accessory spline misalignment gage was designed to fit the mating accessory pads with a pilot diameter of 4.122 in. (AND 10262, AND 10267, and MS 3332). The control module was designed as a general-purpose component, suitable for use with either one of the two gages for the specific pad size chosen, as well as for other gages which may be fabricated for other pad sizes in the future.

The gaging system was found to function satisfactorily in an official demonstration held at the Naval Air Rework Facility, North Island, California, on October 22 and 23, 1975. It is deemed suitable for use at the Depot Level Maintenance.

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I. INTRODUCTION

1. General

The objective of this program was to design and fabricate a spline misalignment gaging system for measuring the aircraft engine gearbox-to-spline and accessory-to-spline misalignments. This report describes the design and operating principle of the gaging system, as well as the procedures for making the necessary measurements and calculating the lateral (concentricity) and angular (squareness) misalignments at the gearbox-to-spline and accessory-to-spline interfaces.

The gaging system comprises, in essence, a gearbox spline misalignment gage, an accessory spline misalignment gage, and a control module containing an amplifier, an indicator, and a recorder. As will be seen later, the current AND and MS Standards cover several different sizes of gearbox and accessory pads. In order to fit all these sizes, several sets of gearbox and accessory spline misalignment gages are required. In this program, a popular pad size was selected for initial development. The specific gearbox spline misalignment gage was designed for use on gearbox pads with a pilot diameter of 4.125 in. and a bolt circle diameter of 5 in. (AND 20002, AND 20007, and MS 3327). The specific accessory spline misalignment gage was designed to fit the mating accessory pads with a pilot diameter of 4.122 in. (AND 10262, AND 10267, and MS 3332). The control module was designed as a general-purpose component, suitable for use with either one of the two gages for the specific pad size chosen, as well as for other gages which may be fabricated for other pad sizes in the future.

During the initial development of the gaging system, a gearbox and mating accessory unit was made available to the program by the San Antonio Air Logistics Center, Kelly Air Force Base, Texas. Later, another unit was received from the Naval Air Supply, Philadelphia, Pennsylvania. Finally, having checked out the functionality of the instrument in the laboratory, an official demonstration was held at the Naval Air Rework Facility, North Island, California, on October 22 and 23, 1975. During the two-day demonstration, measurements were made on three gearboxes and one accessory. Some of the results from these measurements will be cited later in this report to illustrate how the lateral and angular misalignments may be calculated from the basic measurements. The instrument was found to function satisfactorily during the demonstration, and could easily ascertain whether or not the concentricity and squareness on the units checked were within the specified limits. The instrument was therefore deemed suitable for use at the Depot Level Maintenance.

2. Background and Discussion

In a recent survey and analysis of aircraft spline failures,* the importance of effectively controlling spline misalignment in the interests of extending spline life, improving spline reliability, and reducing overall maintenance cost was clearly emphasized. However, it was found during the survey that spline misalignment was not measured, and therefore not controlled, in the rework process within the Navy. Misalignment accelerates spline wear in an exponential fashion and can also cause spline fatigue and/or other damages to the connected equipment. Therefore, effective control of spline misalignment is absolutely needed and must not be taken for granted. Obviously, there can be no real misalignment control unless the misalignment can be measured in the first place. This can be done conveniently and accurately by measuring the misalignments of the interface spline used on the engine accessory gearbox and the interface spline used on the mating accessory.

Lateral (concentricity) and angular (squareness) misalignments for interface splines on engine gearboxes and accessories are specified in various AND and MS Standards, as follows:

Gearbox		Accessory	
AND	Type	AND	Type
20000	X	10260	X
20001	XI	10261	XI
20002	XII	10262	XII
20003	XIII	10263	XIII
20006	XVI	10266	XVI
20007	XVII	10267	XVII
20010	XX	10270	XX
MS	Type	MS	Type
3325	2.653 BC Square	3330	2.653 BC Square
3326	5.000 BC Square	3331	5.000 BC Square
3327	5.000 BC Round	3332	5.000 BC Round
3328	8.000 BC Round	3333	8.000 BC Round
3329	10.000 BC Round	3334	10.000 BC Round

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* Valtierra, M. L., Brown, R. D., and Ku, P. M., "A Critical Survey and Analysis of Aircraft Spline Failures," Final Report, Contract N00156-70-C-2156, submitted to Naval Air Engineering Center, Philadelphia, Pennsylvania, August 18, 1971.

It has often been tacitly assumed that if the splined parts, gearboxes, and accessories are made in accordance with the Standards, then any resulting assembly will have misalignments within the specified limits. This may be true for new engine installations being assembled for the first time. However, as shown by the results of the official demonstation to be cited later, it is certainly not true in the rework process when different new and/or reworked splines, gearboxes, and accessories are being assembled together. Therefore, in the rework process, it is imperative that the spline-to-gearbox and spline-to-accessory misalignments should be carefully checked and, if found in excess of the values specified, should be corrected by appropriate means.

Correcting the concentricity and squareness of the spline-to-gearbox alignment could be accomplished, for example, by boring out the gearbox pilot diameter and inserting a fixed sleeve. The sleeve would then be bored out concentric and square with the bearing pilot diameter and mounting face, respectively. Correcting the spline-to gearbox alignment can be even simpler if the alignment is within the concentricity limits but not within the squareness limits. In this case, the mounting face could be refaced square with the centerline of the female spline.

Correcting the concentricity and squareness of the spline-to-accessory alignment could be accomplished by machining the existing boss down and attaching a sleeve over the boss. The fixed sleeve could then be machined concentric with the bearing pilot diameter and square with the mounting pad.

II. SPLINE MISALIGNMENT GAGES

1. General

The complete spline misalignment gaging system is shown in Figure 1. Illustrated on the left is the carrying case containing a gearbox spline misalignment gage, a magnetic base lamp, and an accessory spline misalignment gage. All items in the carrying case are custom-fitted and shock-mounted in plastic foam for protection and ease of shipment.

The control module shown on the right contains the amplifier, indicator, and recorder. A separate shipping box for the control module (not shown) is also provided.

2. Mechanical Details

The gearbox spline misalignment gage is for use on the 4.125-in. diameter pilot pads of aircraft accessory gearboxes designed under the following Standards:

AND 20002
AND 20007
MS 3327

The accessory spline misalignment gage is for use on the mating accessory having a 4.122-in. pilot diameter, as specified by the following Standards:

AND 10262
AND 10267
MS 3332

The two spline misalignment gages are identical except for their mounting flanges. Both are used with the same control module containing an amplifier, an indicator, and a recorder. Only one of the spline misalignment gages will be described in detail. The principal parts of the gearbox spline misalignment gage are identified in the assembly drawing shown in Figure 2, and all of the mechanical parts for both spline misalignment gages are listed in Table 1.

The principle of operation of the gearbox spline misalignment gage consists of first attaching the gage stand to the gearbox, then aligning the gaging centerline until it is coincident with the centerline of the gearbox pilot bore, and then sliding the probe tip up and down the

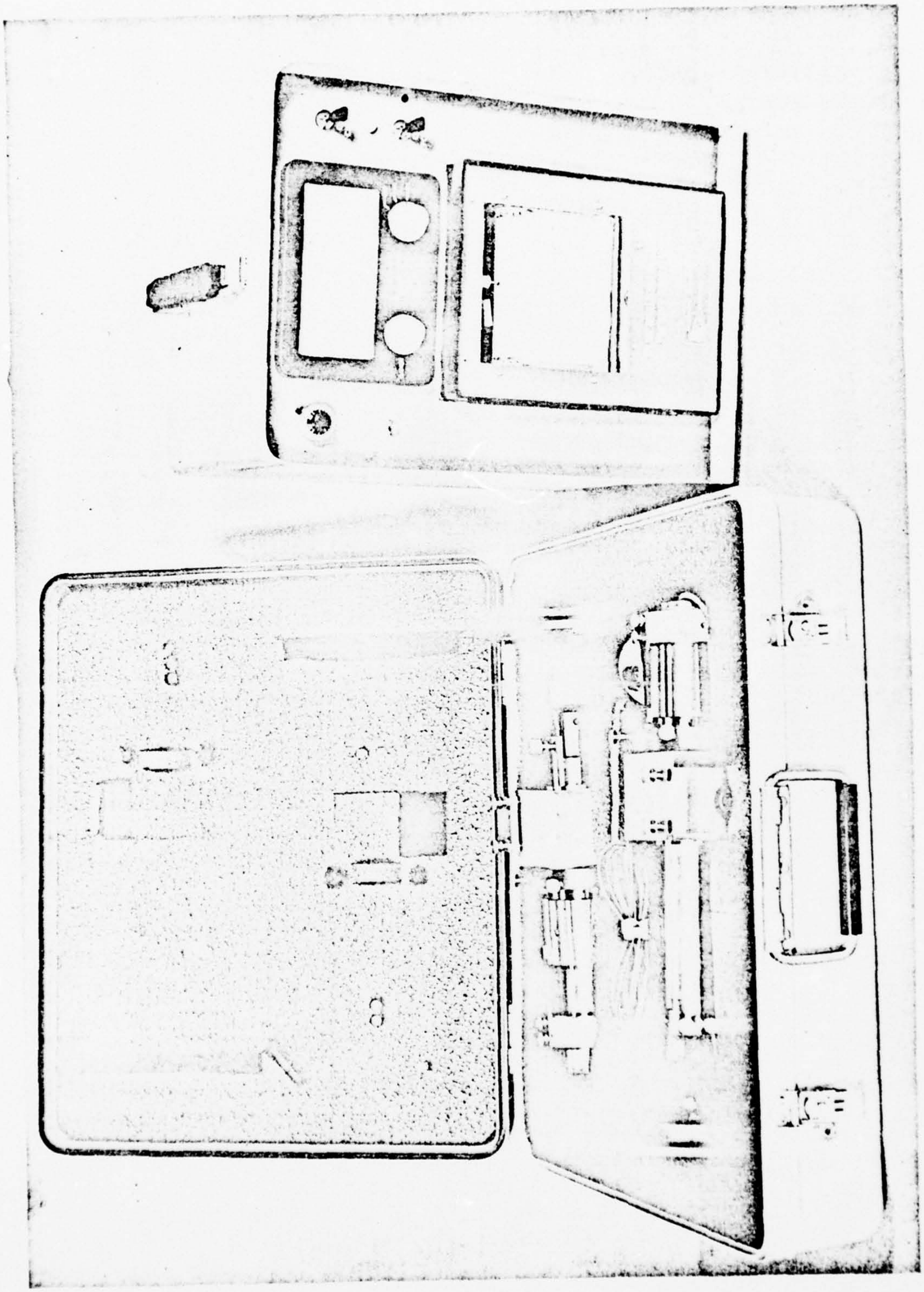


FIGURE 1. SPLINE MISALIGNMENT GAGING SYSTEM

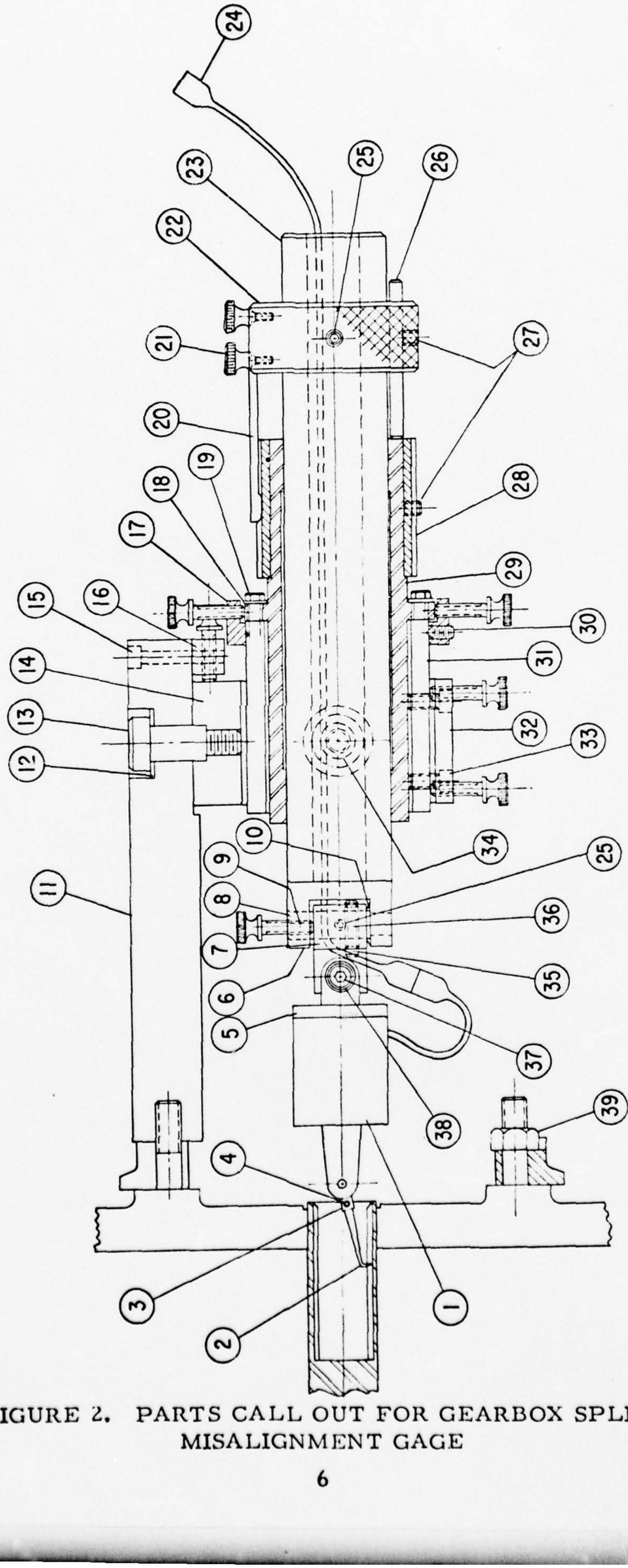


FIGURE 2. PARTS CALL OUT FOR GEARBOX SPLINE MISALIGNMENT GAGE

TABLE 1. PARTS LIST FOR GEARBOX AND ACCESSORY SPLINE MISALIGNMENT GAGES

Part No.	Description	Quantity
1	Gage head, Federal EHE - 1048	1
2	Probe tip	1
3	Probe positioner	1
4	Set screw, 2-56 x1/8	1
5	Conversion bracket	1
6	Mounting block	1
7	Positioning bracket	1
8	Pivot	1
9	Thumbscrew, 10-32 x 3/4	10
10	Belleville washer, Associated Spring Corp. B0750-028-S	2
11	Stand	1
12	Belleville washer, Associated Spring Corp. B1000-050	2
13	Shoulder screw, Jergens 41716	1
14	Pivoted angle	1
15	Socket head cap screw, 10-24 x 1-1/4	2
16	Stand bracket	1
17	Lateral adjustment ring	1
18	Washer	4
19	Hex bolt	4
20	Indexing finger	1

TABLE 1. PARTS LIST FOR GEARBOX AND ACCESSORY SPLINE MISALIGNMENT GAGES (Con't)

Part No.	Description	Quantity
21	Flat head screw, 4-40 x 1/4	2
22	Knob	1
23	Traversing rod	1
24	Cable	1
25	Set screw, 10-32 x 1/2	1
26	Depth adjusting pin	1
27	Set screw, 10-32 x 1/4	2
28	Indexing collar (one with 8 slots, one with 7 slots)	2
29	Traversing rod guide	2
30	Cone-point set screw, 10-32 x 3/8	1
31	Pivoted block	1
32	Alignment angle bracket	1
33	Socket head cap screw, 10-32 x 1/2	2
34	Shoulder screw, Jergens 41715	1
35	Set screw, 10-32 x 3/4	1
36	Spring plunger, Jergens 26903	1
37	Socket head cap screw, 1/4-28 x 7/8	1
38	Washer	1
39	Hex nut, 3/8-24	6
40	Threaded bolt, 3/8-24 (for accessory spline misalignment gage only)	6

spline grooves to obtain the quantitative measurements needed to determine the extent of misalignment between the spline and the gearbox pilot bore. The same principle is used on the accessory spline misalignment gage.

The function of each of the major parts identified in Figure 2 is described below:

The gage head (1) is of the variable inductance type. The probe tip (2) is especially designed to fit in the spline grooves and can be rotated about its axis for centering, by loosening the small set screw (4) in the probe positioner (3).

The position of the gage head (1) can be adjusted in three directions by means of the cap screw (37), thumbscrew (9), and set screw (35).

Angular alignment of the gearbox spline misalignment gage centerline can be adjusted by loosening shoulder screws (13 and 34) and manipulating the thumbscrews in the stand bracket (16) and alignment angle bracket (32).

The lateral position of the gage centerline can be adjusted by loosening the hex bolts (19) and manipulating the thumbscrews in the lateral adjustment ring (17). The depth of probe traverse can be set by means of the depth adjusting pin (26) and set screw (27). In order to maintain the relative position of the probe tip in each of the spline grooves, two indexing collars (28), are provided. One of these collars has eight equally spaced slots and is intended for use with either 16- or 24-tooth splines. The other collar has seven slots and is intended for use with 26-tooth splines. In practice, the appropriate collar is locked on the traversing rod guide (29) by means of set screw (27).

In order to facilitate changing the gage head from the gearbox spline misalignment gage to the accessory spline misalignment gage, a cable (24) is provided within each traversing rod (23).

3. <u>Electrical Details</u>

The essential electrical controls are shown in Figures 3 and 4. Figure 3 shows the front of the control module. All the controls used in normal operation of the control module are accessible from the front with the recorder door closed. It is generally convenient when using the recorder to leave the door open to permit marking the recorder chart.

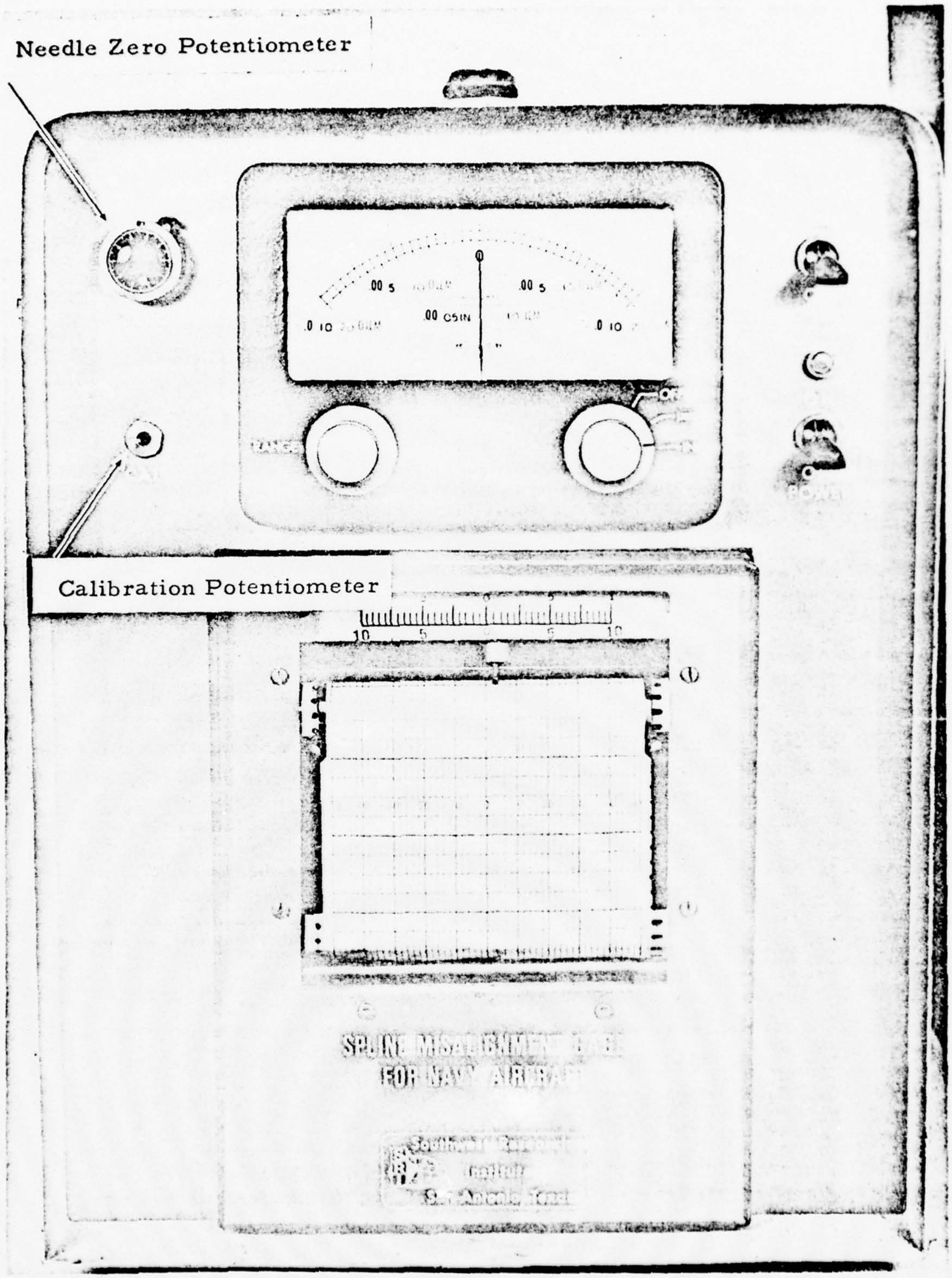


FIGURE 3. FRONT VIEW OF SPLINE MISALIGNMENT CONTROL MODULE

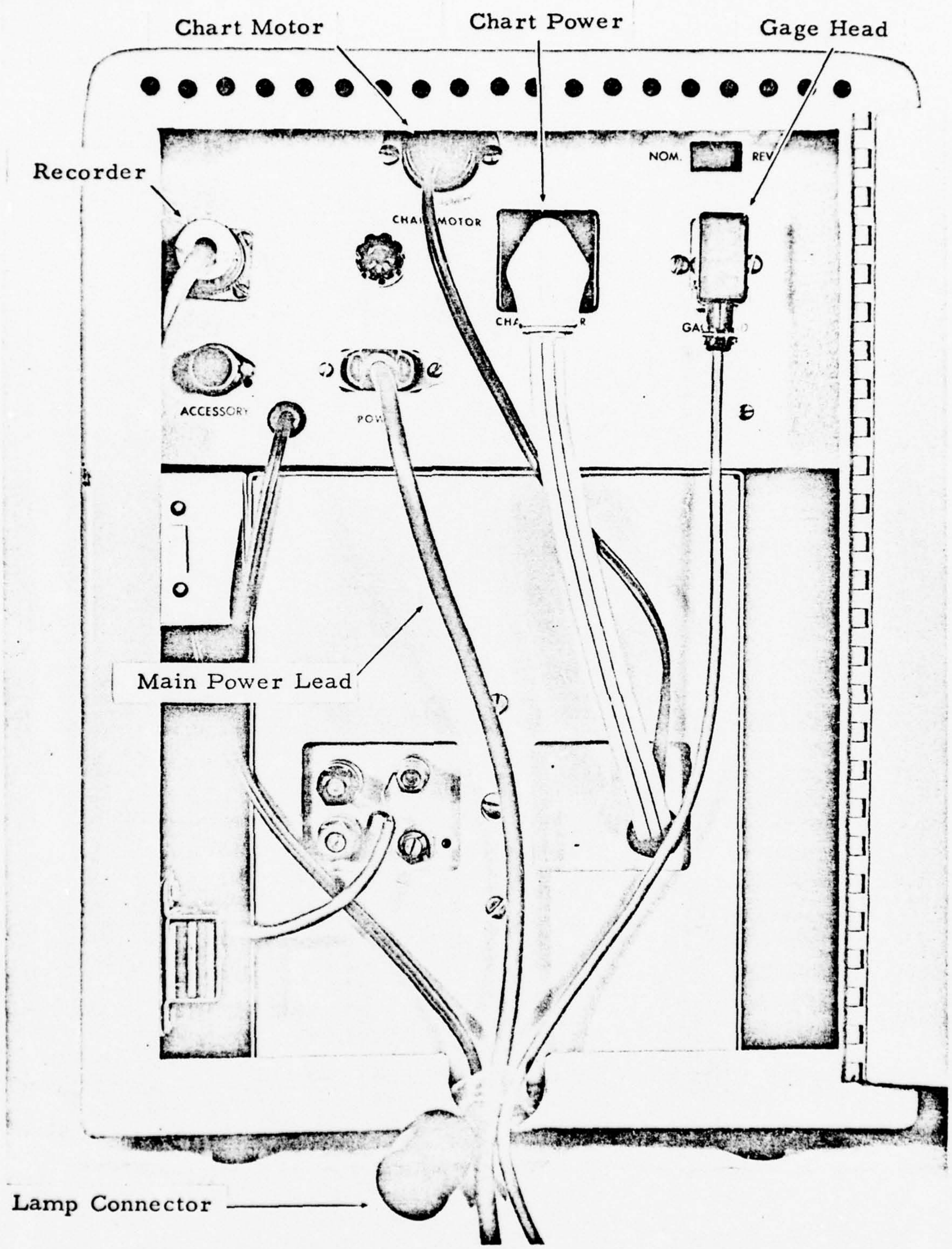


FIGURE 4. REAR VIEW OF SPLINE MISALIGNMENT CONTROL MODULE

The "power" switch controls the power for the amplifier, recorder, and lamp. The "chart" switch controls only the chart drive motor. The chart pen is active whenever the "power" switch is on. It should be noted that the chart pen and the indicator needle will be in the same relative positions if the amplifier and the recorder zero and calibration spans are set properly. The "needle zero" and "calibration" potentiometers are exposed by opening the recorder door. These potentiometers need infrequent adjustments.

The "needle zero" potentiometer will provide for full-scale positioning of the needle on the following scales: ±0.001 in., ±0.002 in., and ±0.004 in. On the ±0.10 in. scale, which is the optimum scale for conducting spline misalignment measurements, the range of needle positioning is only ±0.0055 in. The range of needle positioning is ±0.0027 in. on the ±0.020 in. scale. This scale is normally used in initial positioning of the gearbox or accessory spline misalignment gage on a gearbox or accessory.

Immediately below the "zero" potentiometer is a "calibration" (cal) potentiometer, which is used for calibration of the needle deflection against known displacements of the probe tip. The known displacements can be effected by the use of feeler gages or gage blocks of known displacement or by micrometer devices.

The "range" knob on the left-hand side of the indicator is used in selecting the appropriate scale. Five scales are provided as shown below:

Full-Scale Range	Minimum Graduation
±0.001 in.	0.00005 in.
±0.002 in.	0.00010 in.
±0.004 in.	0.00020 in.
±0.010 in.	0.00500 in.
±0.020 in.	0.00100 in.

The recorder chart divisions are matched with the meter divisions. Full-scale deflection on the chart is ±20 divisions on each scale. Since the chart has ±25 divisions, no "off-scale" deflection problems should occur if the amplifier and recorder are functioning properly.

Additional electronic details for the amplifier (Federal Model EAS-432) and the recorder (Federal Model RE-100) are provided in the instruction booklets in Appendix A.

The electrical connections normally used are shown in rear view of the control module (back door open) in Figure 4. The amplifier fuse and a switch ("nom" or "rev") are also shown. The switch is used for changing the direction of needle deflection. The electronic gage head plugs in at the upper-right location. Plugs have also been provided for the chart power and the chart motor. The recorder plugs into the amplifier at the upper-left location.

A "main power lead" is provided with a "lamp connector" at the lower center of the control module.

III. PROCEDURE FOR GEARBOX SPLINE MISALIGNMENT MEASUREMENTS

The procedure for making gearbox spline misalignment measurements is as follows:

1. Initial Set-up

a. Remove gearbox spline misalignment gage from carrying case, see Figure 1.

b. Rotate probe tip (2) upward to clear base of stand (11).

c. Place gearbox spline misalignment gage with knob (22) up on a flat surface.

Note: Care must be taken to keep traversing rod (23) from moving downward to prevent damage to probe tip (2) and gage head (1).

2. Make Electrical Connections

a. Connect the power cord from control module to 115 VAC outlet.

b. Connect the gage head (1) to cable (24), see Figure 5.

c. Connect cable (24) to the amplifier cable protruding from the rear of the control module.

3. Square Gearbox Spline Misalignment Gage on Flat Surface

a. Set stand on clean flat surface plate, see Figure 6.

b. Remove indexing finger (20) by loosening and removing adjacent thumbscrews.

c. Hold knob (22) and loosen set screw (27) located adjacent to depth adjusting pin (26) allowing traversing rod to move downward until probe tip (2) is in contact with surface plate.

d. Tighten set screw (27).

e. Turn on amplifier (amplifier "power light" on).

f. Set needle "zero" potentiometer to "5" in window.

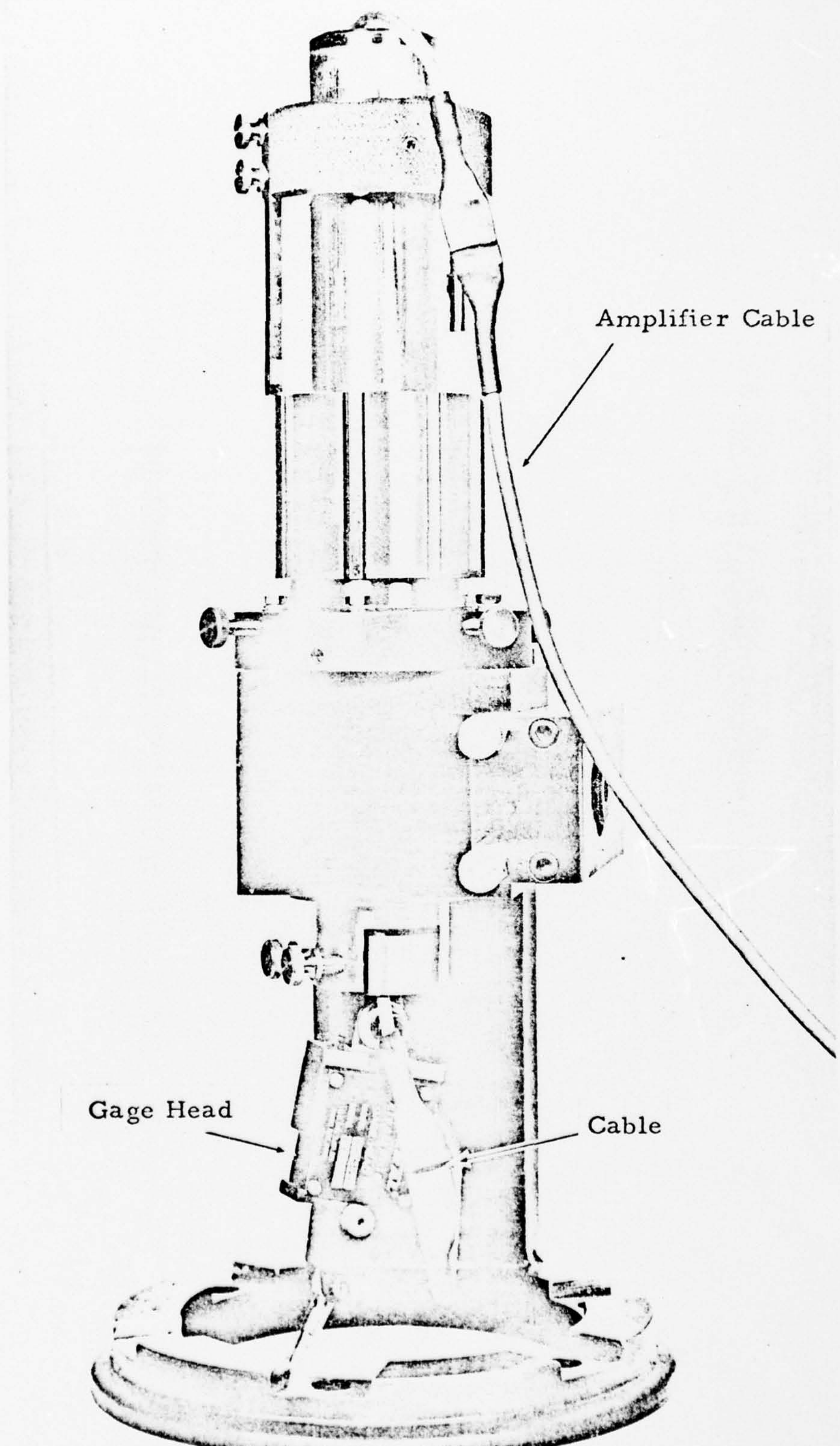


FIGURE 5. CONNECT GAGE HEAD TO CABLE

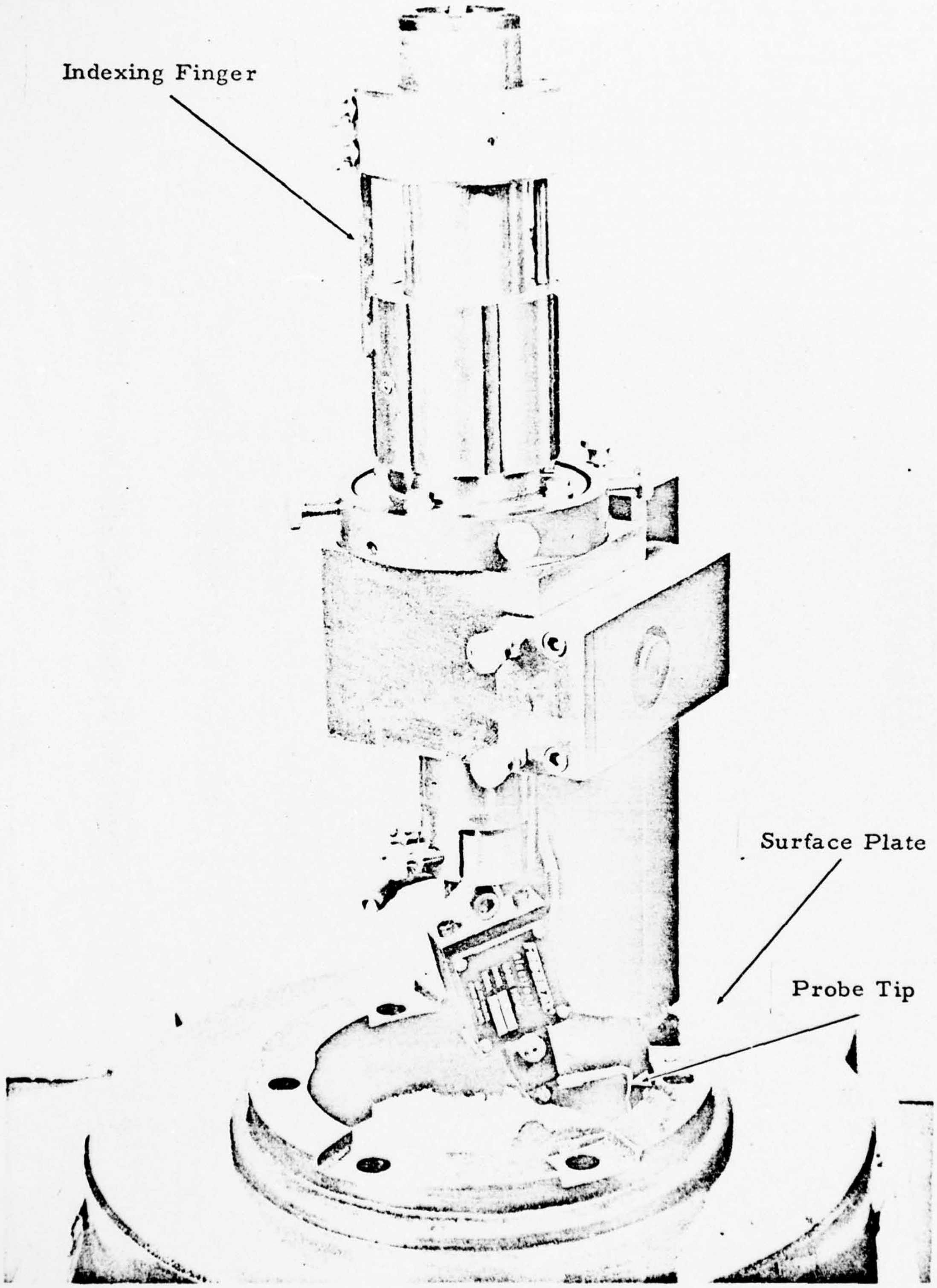


FIGURE 6. SQUARE GAGE ON FLAT SURFACE

g. Adjust the position of the gage head until the needle is near the middle of the ±0.020 in. scale by moving gage head.

h. Set needle on zero with "needle zero" potentiometer.

i. Rotate the probe tip through 360° to see the approximate amount and direction of misalignment.

j. Position the probe tip so it is directly opposite the stand (adjacent to the operator) and note needle or recorder deflection. Rotate the probe tip 180° and note gage deflection.

k. Slightly loosen the shoulder screw (34) in pivoted angle (14), if necessary.

ℓ. Adjust thumbscrews on (32) until gage deflection is midway between the deflections noted in step j.

m. Repeat steps j and k until the same deflection occurs at the 0° and 180° position.

n. Tighten jam nuts on thumbscrews (32) and shoulder screw (34).

o. Rotate the probe tip (2) to the 90° position, note needle deflection, then rotate the probe tip to the 270° position and note the deflection.

p. Loosen the shoulder screw (13) in the stand (11).

q. Adjust thumbscrews in (16) until gage deflection is midway between the deflections noted in step o.

r. Repeat steps o and q until the same deflection occurs at the 90° and 270° positions.

s. Rotate probe tip through 360°, if the TIR (total indicator reading) exceeds 0.0005 in. repeat steps i through r as needed to reduce the TIR. At this point the sensitivity of the gage can be increased by switching to one of the more sensitive scales, ±0.010 in. or ±0.004 in.

t. Once TIR is less than 0.0005 in. retighten shoulder screws (13) and (34).

4. Set Gearbox Spline Misalignment Gage on Gearbox

Note: The centerline of the gearbox spline can be horizontal or vertical (horizontal measurements are easier to perform).

a. Thoroughly clean gearbox pad and spline from any foreign matter. Remove sharp burrs from gearbox pad and pilot.

b. Set gearbox spline misalignment gage on gearbox pad and position over existing studs—Note: Caution must be used not to damage gage probe (2) and gage head (1) during this step, see Figure 7.

c. Place nuts (39) over studs and hand tighten.

5. Install Lamp

a. Attach magnetic base of lamp to upright portion of stand (11).

b. Plug lamp cord into connector at rear of control module.

c. Position light toward gearbox pad.

6. Center Gearbox Spline Misalignment Gage on Pilot Bore

a. Plug in amplifier cable.

b. Turn on amplifier power switch.

c. Set range to the ±0.020 in. scale.

d. Position probe tip in gearbox pilot bore as shown in Figure 7.

e. Make sure that traversing rod guide (29) is approximately in the center of the pivoted block (31). If centering is required, loosen hex bolts (19) and center guide with the four thumbscrews in lateral adjustment ring (17).

f. Slide the base of the stand around until the needle is deflected near the middle of the ±0.020 in. scale.

g. Note the gage or recorder deflection with the probe tip at the 0° and 180° position.

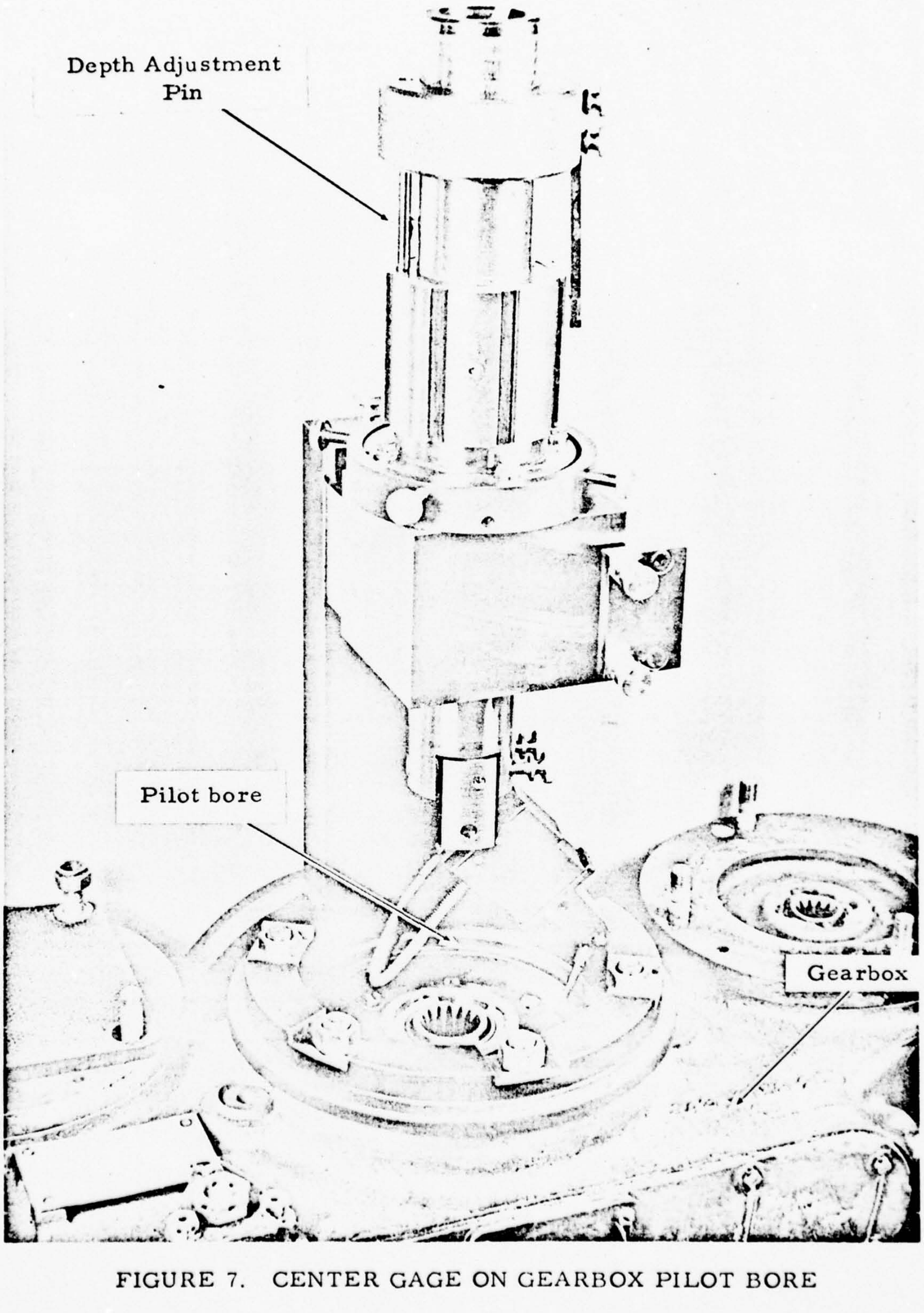


FIGURE 7. CENTER GAGE ON GEARBOX PILOT BORE

h. Move the stand by hand until gage deflection is "midway" between the deflections noted in step g.

i. Repeat step g with the probe tip in 90° and 270° positions.

j. When maximum TIR (during 360° probe traverse) is less than 0.005 in., tighten all gearbox nuts (39) to clamp the stand onto the gearbox.

k. Loosen hex bolts (19).

ℓ. Use the four set screws in lateral adjustment ring (17) to adjust the position of the traversing rod guide (29) until the TIR during a 360° traverse is less than 0.0005 in. (it may be desirable to use the ±0.010 in. scale for this purpose).

m. Retighten hex bolts (19).

7. Position Probe Tip in Spline Groove

a. Reset depth pin (26) and knob (22), if necessary, so that the probe tip is about 1/16 in. below the upper end of the spline, see Figure 8.

b. Position the probe tip so that it contacts the "middle" of one of the spline grooves (major diameter of the spline teeth) with the probe shank nearly parallel to spline teeth. This can be accomplished by loosening set screw (4) and rotating the tip until it is centered in the groove and/or by loosening set screws (25A) on the positioning bracket (7) and adjusting probe tip position by means of set screws (35). It may also be advantageous to rotate the female spline to be measured from an adjacent female spline pad to engage the probe tip into the spline.

8. Lock Indexing Collar

a. Loosen set screw (27) on indexing collar (28).

b. Install indexing finger (20) with thumbscrews (21).

c. Rotate indexing collar (28) until the indexing finger (20) slips into "slot No. 1" identified by "white mark" on indexing collar, see Figure 9.

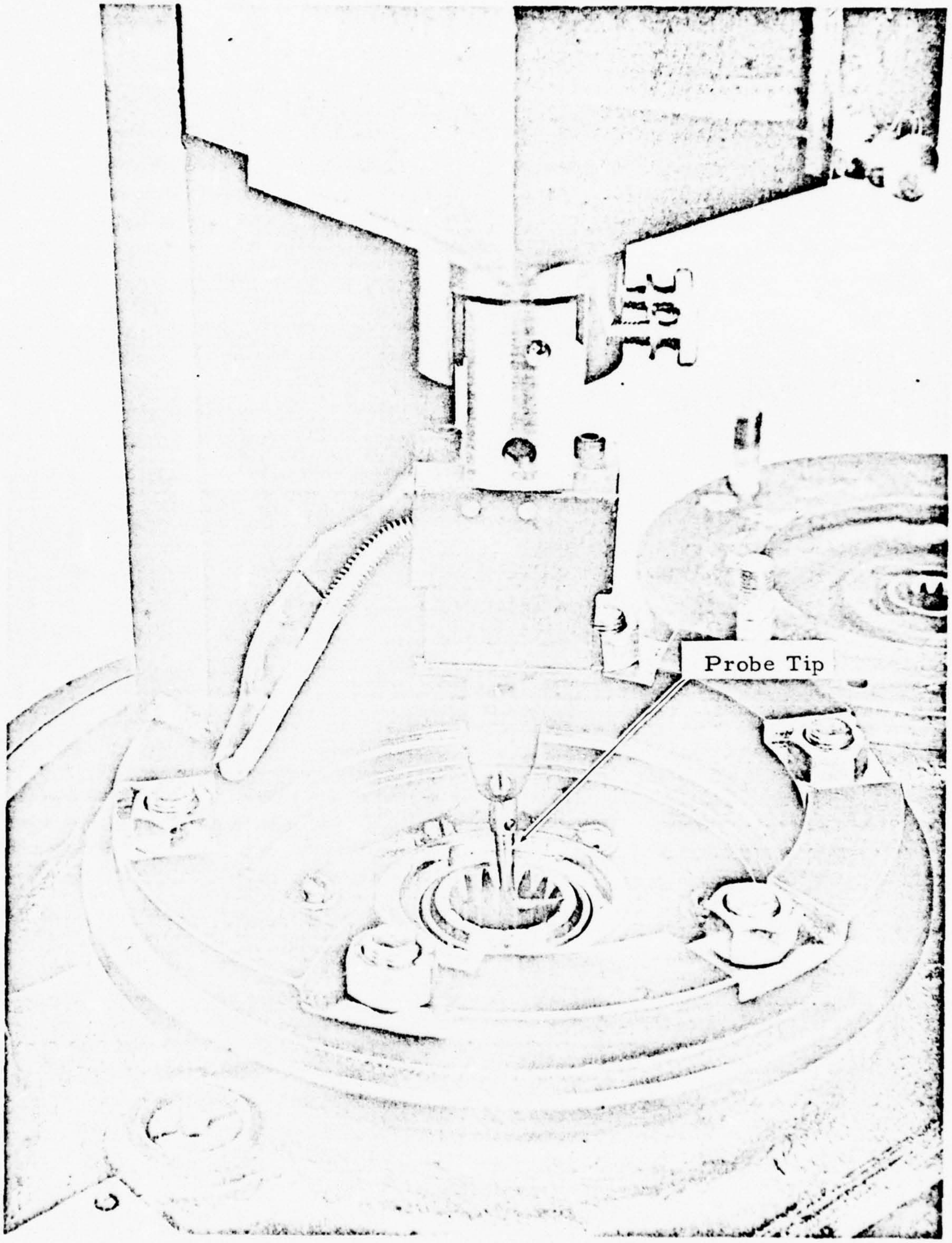


FIGURE 8. POSITION PROBE TIP IN SPLINE GROOVE

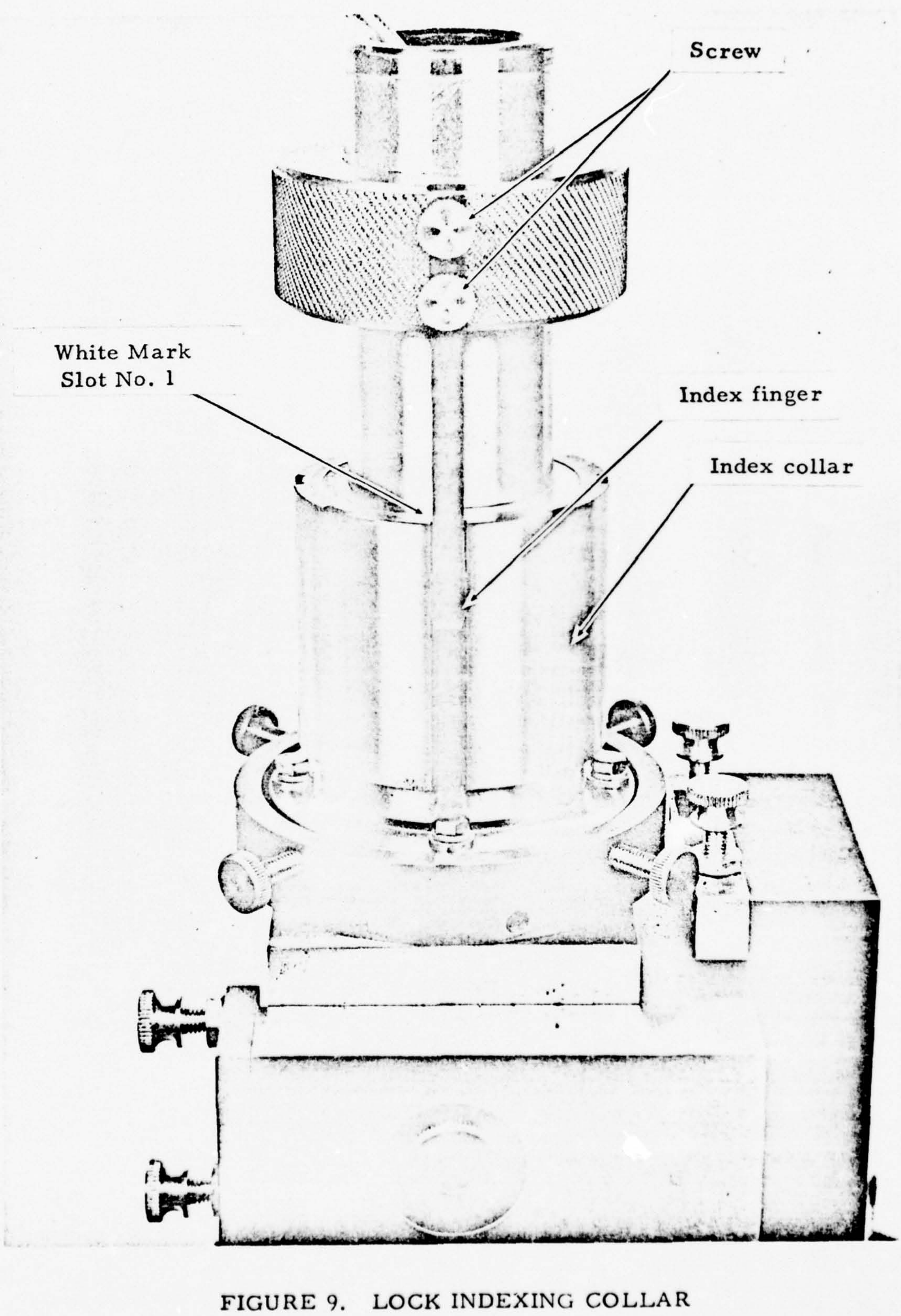


FIGURE 9. LOCK INDEXING COLLAR

d. Tighten thumbscrews (21) to hold indexing finger in place.

e. Raise traversing rod (23) and adjust the height of the knob (22) until the probe tip (2) is near the upper end of the spline when the indexing finger (20) is near the upper end of the indexing collar (28).

f. Tighten set screw (25) in knob (22).

9. Set Probe Tip in Lower Position

a. Place depth adjusting pin (26) in contact with traversing rod guide (29), see Figure 7.

b. Loosen set screw (27) on knob (22) and allow the traversing rod (23) to slide down until the probe tip is at the desired spline depth (no less than 1/2 in.).

c. Lock set screw (27) on knob (22).

10. Adjust Probe Engagement in Spline Groove

a. Set the "range" selector to the ±0.010 in. scale.

b. Loosen cap screw (37) and rotate gage head until needle deflection is near the center of the indicator.

c. Tighten cap screw (37).

d. Adjust needle deflection by means of "zero" potentiometer on the amplifier to center of chart.

11. Misalignment Measurements

a. Turn on power switch ("recorder light" on). Use "zero" adjustment on recorder to make necessary adjustments so that the recorder pen deflection corresponds with that of the needle on the indicator.

b. Near the trace on the recorder paper, write slot number and probe position (for example, "1B" means slot "one" in "bottom" position).

c. Turn on chart switch.

d. Raise the traversing rod (23) until the probe tip (2) is near the top of the spline and hold for several seconds to get the "top" trace on Slot No. 1.

e. Raise the traversing rod (23) so that the indexing finger (20) is free of the slot. Rotate the knob (22) and engage the indexing finger (20) in the next slot. Allow the traversing rod to slide down to its "bottom" position.

f. Label the two traces on the recorder chart (for example, "1T" means slot one in "top" position and "2B" means slot two in "bottom" position).

g. Repeat steps d through f until the indexing finger (20) is back in the original Slot No. 1 position.

12. Typical Recorder Traces

The objective of interpreting the recorder traces is to determine the "concentricity" and "squareness" of the spline relative to the gearbox pilot diameter and gearbox mounting face, respectively. Sample charts have been prepared to illustrate the type of traces which may be obtained depending upon the exact misalignment condition. For example:

a. Misalignment: Spline Not Concentric—Spline Square

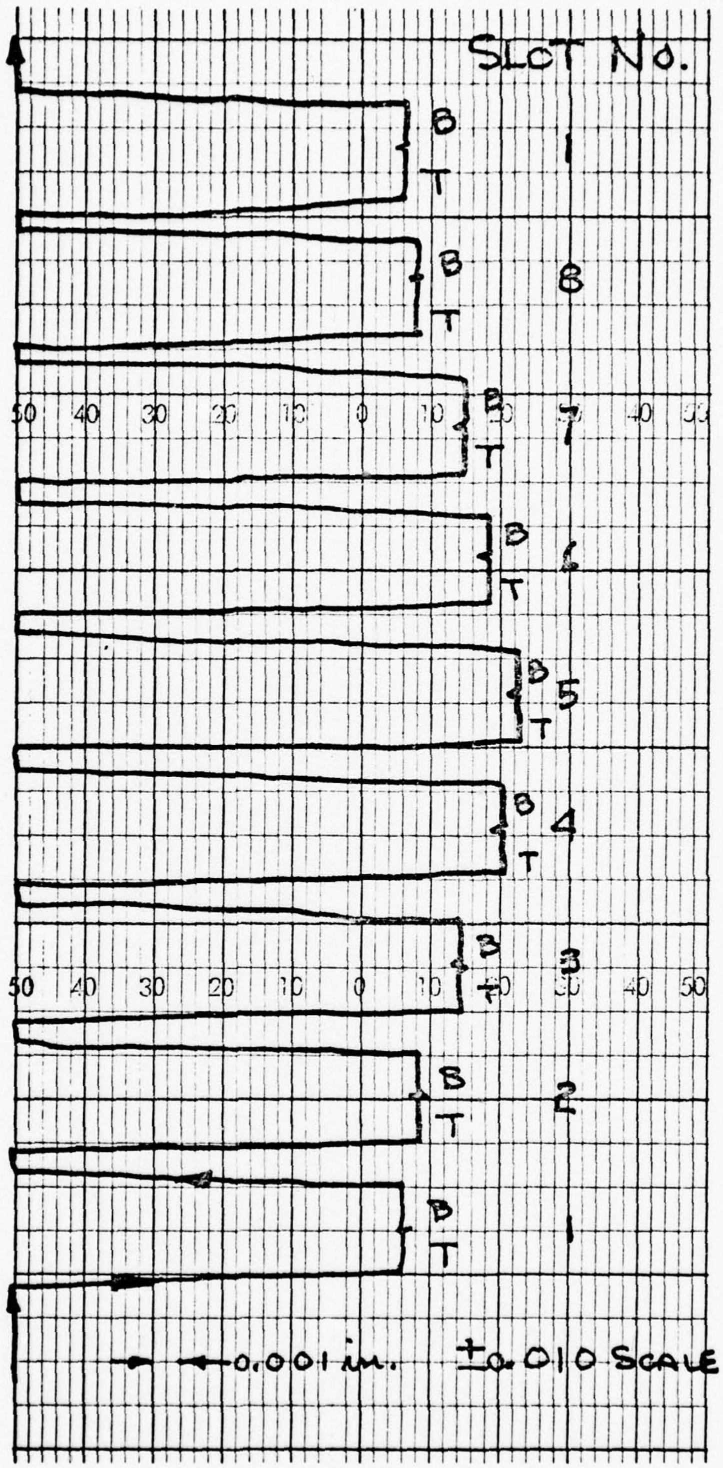
In Figure 10, the traces represent those obtained for a spline having a lateral misalignment (spline not concentric) of 0.002 in. (i.e., centerlines of spline and pilot bore displaced 0.002 in.) corresponding to 0.004 in. TIR (total indicator reading).

The absence of angular misalignment (spline square) is indicated by the fact that in each of the slot measurements, the "T" and "B", i.e., the top and bottom measurements, are the same. As will be shown in later examples, angular misalignment will cause a displacement between the "top" and "bottom" measurements in most of the slots.

The amount of lateral misalignment in Figure 10 is expressed as TIR and is the "difference between the extreme traces." In this case, the traces for Slots Nos. 1 and 5 are separated by 8 chart lines, which corresponds to 0.004 in. on the ±0.010 in. scale.

b. Misalignment: Spline Concentric—Spline Not Square

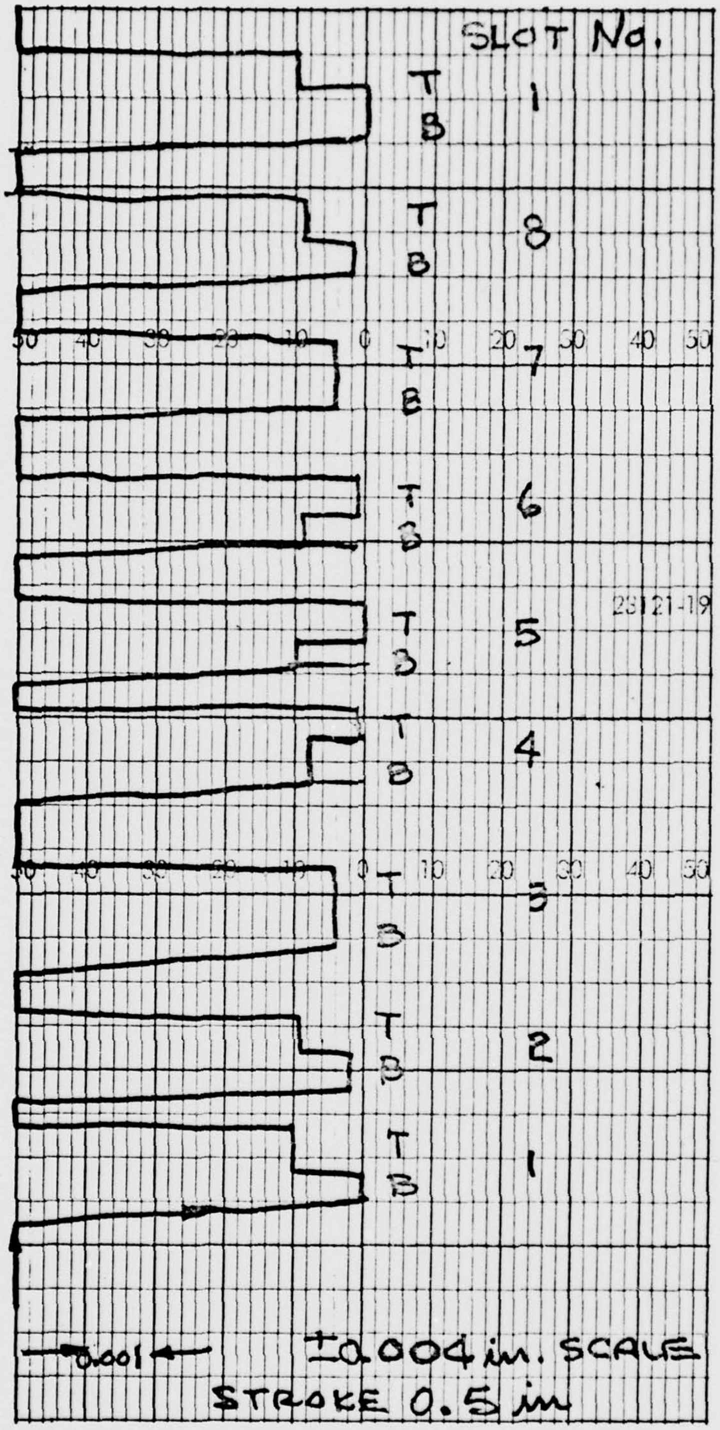
Figure 11 illustrates the trace for a spline that is concentric with the gearbox pilot but does have angular misalignment (spline not square).



MISALIGNMENT

Concentric (Lateral)= 0.002 in. (0.004 TIR)
Square (Angular) = 0 in./in.

FIGURE 10. TRACE FOR SPLINE NOT CONCENTRIC—SPLINE SQUARE



MISALIGNMENT

Concentric (Lateral) = 0
Square (Angular) = 0.002 in./in.

FIGURE 11. TRACE FOR SPLINE CONCENTRIC— SPLINE NOT SQUARE

The mount of angular misalignment can be determined from the trace exhibiting the greatest difference between the "T" and "B" measurements. In this case, the "T" and "B" traces for Slots Nos. 1 and 5 are separated by 5 chart lines, which corresponds with 0.001 in. on the ±0.004 in. scale. The squareness or angular misalignment is given by the following equation:

$$\text{Squareness (angular misalignment)} = \frac{0.001 \text{ in.}}{0.50 \text{ in.}} = 0.002 \text{ in./in.}$$

where 0.50 in. is the tip travel or stroke.

c. Misalignment: Spline Not Concentric—Spline Not Square

Figure 12 depicts the trace for a spline that is not concentric (lateral misalignment) and is not square (angular misalignment). A large variety of traces can result from combined misalignments.

In this example, the concentricity is represented by the difference between the two largest "top" readings, i.e., Slots Nos. 5 and 1 are separated by 20 chart lines, which is equal to 0.004 in. The largest angular misalignment is noted on Slot No. 3 (0.001 in.). The squareness will then be 0.001 in. ÷ 0.50 in., or 0.002 in./in.

13. Data Sheet

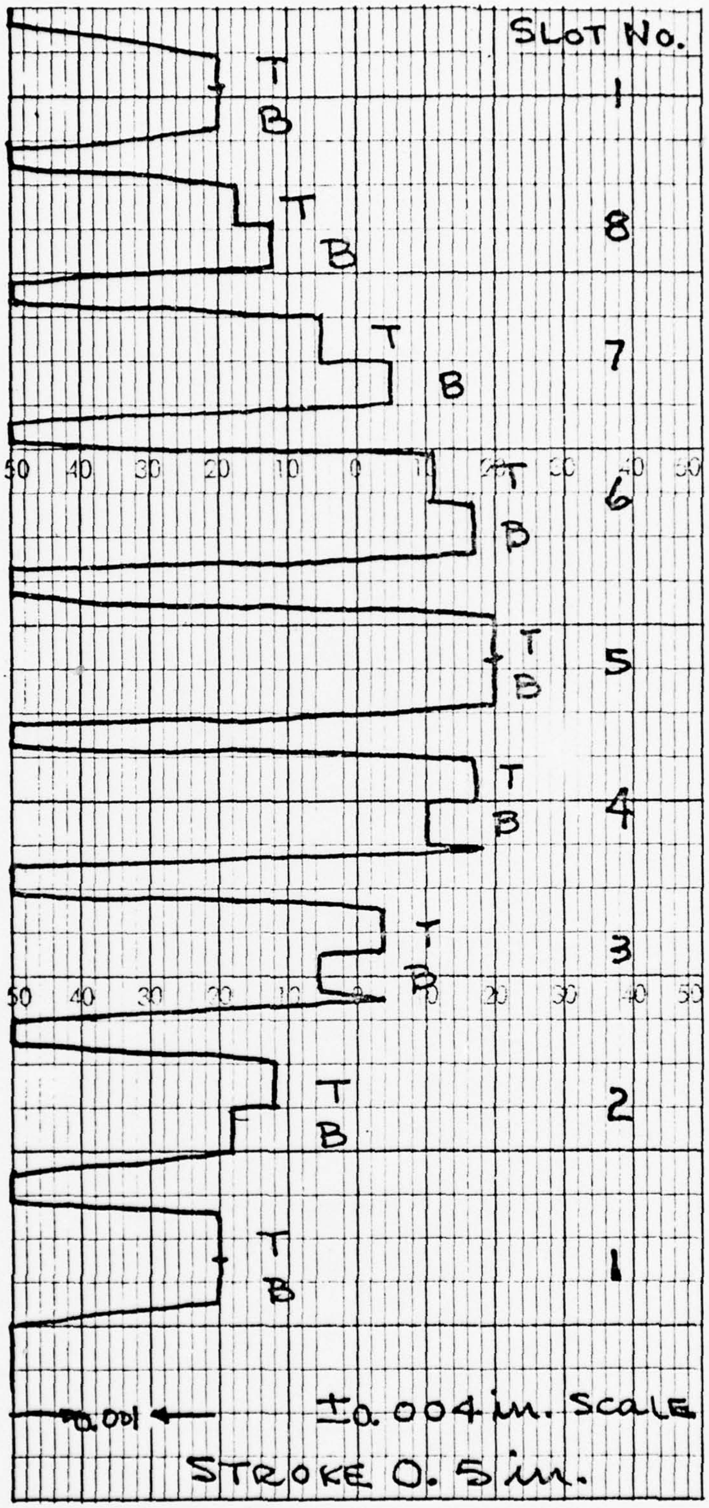
Figure 13 illustrates the data sheet which has been designed for use with the gearbox or accessory spline misalignment measurements. Actual data have been included in the data sheet to facilitate the presentation.

The test number, scale used on the control module, pad number, and number of spline teeth are recorded. Other information is also included. The original recorded data is also presented in Figure 14.

The concentricity of the spline relative to the pad is the first item to check. As mentioned earlier, the concentricity will be the maximum difference between two top readings. In this case, the largest difference in top readings between Slot No. 1 and Slot No. 7* was 0.005 in.

---

* The gearbox and accessory spline misalignment gages use an indexing collar having 8 slots for measuring a spline having 16 teeth. The Slot No. 7 position will then correspond to Tooth No. 13.



MISALIGNMENT

Concentric (Lateral)= 0.002 in. (0.004 TIR)
Square (Angular) = 0.002 in./in.

FIGURE 12. TRACE FOR SPLINE NOT CONCENTRIC → SPLINE NOT SQUARE

GEARBOX —OR— ACCESSORY SPLINE MISALIGNMENT

NARF North Island Bldg. 472 Date 10-22-75

Aircraft H-3 Engine Pad for (UNK)

Gearbox/~~Accessory~~ Main H-3 Pad Size 4.125

Part No. S6135-22000-4 Bolt Circle 5

Serial R14-1-28-67-798 Operator M. Valtierra (SwRI)

Test / Scale	Pad No. / No. of Teeth	Concentricity: Pass < 0.0051, Fail >0.006 — Slot No.	Amount ΔT. max in.	Pass Fail	Squareness: Pass < 0.00085, Fail > 0.001 (.06°) — Slot No.	ΔTB_{max} in.	Stroke in.	Amount in./in.	Amount deg.	Pass Fail
1 / ± 0.010	1 / 16	7	0.005	Pass	3	0.00575	0.75	0.0077	0.44	Fail
2 / ± 0.010	1 / 16	7	0.005	Pass	3 & 4	0.006	0.75	0.008	0.46	Fail
3 / ± 0.010	2 / 16	6 & 7	0.00225	Pass	8	0.0055	0.75	0.0073	0.42	Fail
4 / ± 0.010	2 / 16	7	0.00325	Pass	8	0.0055	0.75	0.0073	0.42	Fail

Sketch -

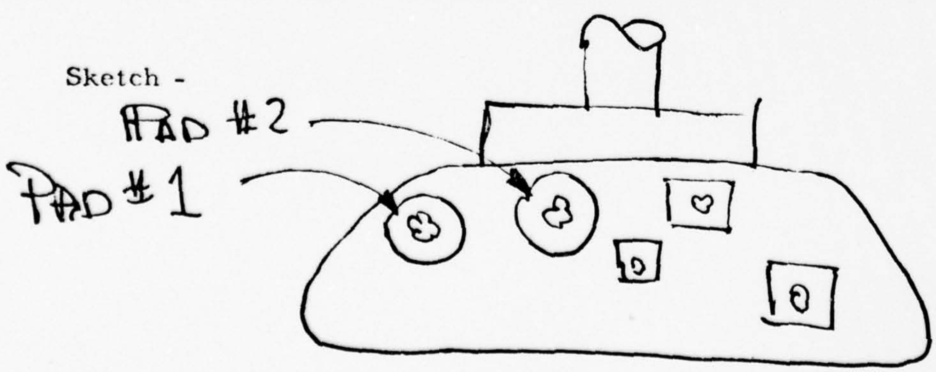


FIGURE 13. DATA SHEET FOR USE WITH GEARBOX SPLINE MISALIGNMENT MEASUREMENTS

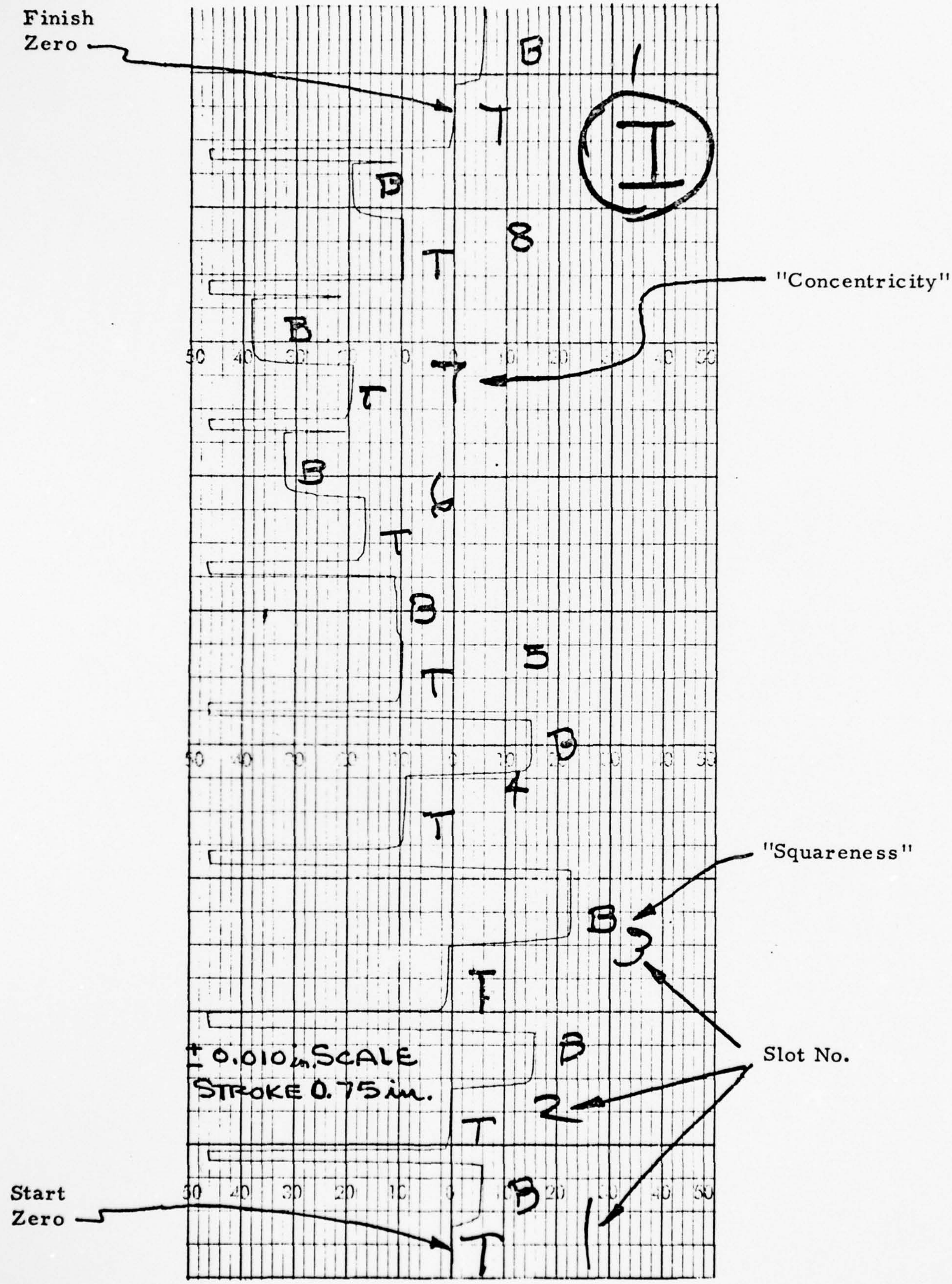


FIGURE 14. ORIGINAL RECORDED GEARBOX SPLINE MISALIGNMENT DATA

The squareness data from Figure 14 shows the largest difference between top and bottom readings ($\Delta TB_{max.}$) on a particular tooth, which was 0.00575 in. for Slot No. 3. The stroke used was 0.75 in. The squareness or angular misalignment in in./in. is obtained by dividing the "stroke" into the "$\Delta TB_{max.}$" yielding 0.0077 in./in. (which is equivalent to 0.44 deg.).

14. Pass-Fail Criteria

The pass-fail criteria for the "concentricity" and "squareness" specified by the AND and MS Standards for a pad size of 4.125 in. diameter is presented in Tables 2 and 3, respectively. As noted in Tables 2 and 3, if the "concentricity" is >0.006 in., the gearbox fails the concentricity test. Likewise, if the "squareness" is >0.001 in./in., the gearbox spline fails the squareness test.

The pass criteria is somewhat more complicated because of the space between the indexing collar slots, the space between adjacent spline grooves, and the fact that the probe does not always traverse those portions of the major diameter cylinder corresponding to the maximum misalignment. For example, when using the 8-slot indexing collar, the point of maximum misalignment can be displaced as much as 22.5° from the slot position. When this occurs, the measured TIR will be less than the misalignment at the point of maximum misalignment. Because of this effect, the interpretation of the readings becomes more complicated in cases where the spline misalignment is close to the maximum allowable misalignment. In such cases, it may become necessary to perform additional traverses in which the indexing collar is displaced successively one, two, or three spline teeth (corresponding to the 1st, 2nd, and 3rd measurements in Tables 2 and 3). Some of the design considerations and the mathematics involved in setting the pass and fail criteria are given in Appendix B.

TABLE 2. PASS-FAIL CRITERIA FOR CONCENTRICITY (LATERAL MISALIGNMENT) OF SPLINE-TO-GEARBOX PILOT DIAMETER

No. of Teeth	Maximum Allowable Lateral Misalignment, (TIR) in. *	Lateral Misalignment Measurements, in. **					
		1st		2nd		3rd	
		Pass	Fail	Pass	Fail	Pass	Fail
16	0.006	<0.0051	>0.006	<0.0059	>0.006	---	---
24	0.006	<0.0051	>0.006	<0.0058	>0.006	<0.006	>0.006
26	0.006	<0.0053	>0.006	<0.0058	>0.006	<0.006	>0.006

* As specified in AND 20002, AND 20007, and MS 3327

** Lateral (Eccentricity) Measurement = $T_{max} - T_{min} = \Delta T$

where T_{max} = maximum displacement of a "Top" recorder trace

T_{min} = minimum displacement of a "Top" recorder trace

TABLE 3. PASS-FAIL CRITERIA FOR SQUARENESS (ANGULAR MISALIGNMENT) OF SPLINE-TO-GEARBOX PILOT DIAMETER

No. of Teeth	Maximum Allowable Angular Misalignment, in/in. *	Angular Misalignment Measurements, in. **					
		1st		2nd		3rd	
		Pass	Fail	Pass	Fail	Pass	Fail
16	0.001	<0.00085	>0.0010	<0.00096	>0.0010	---	---
24	0.001	<0.00085	>0.0010	<0.00093	>0.0010	<0.00098	>0.0010
26	0.001	<0.00077	>0.0010	<0.00094	>0.0010	<0.00098	>0.0010

* As specified in AND 20002, AND 20007, and MS 3327 $= \dfrac{\text{Square within 0.0040 in.}}{\text{Bore diameter 4.125 in.}}$

$= 0.0009696 \cong 0.001$ in./in. $\cong 0.06°$

** Angular (squareness) Misalignment Measurement $= \dfrac{\Delta TB_{max}}{\text{stroke}}$

where $\Delta TB_{max.}$ = the greatest difference between the top and bottom readings on the same tooth.

Stroke = distance traveled along the tooth, in.

IV. PROCEDURES FOR ACCESSORY SPLINE MISALIGNMENT MEASUREMENTS

The procedures for setting up the accessory spline misalignment gage for measuring misalignment of male splines on accessories are basically identical with those used for the gearbox spline misalignment gage down through step 8 in Section III. The procedure may be stated as follows:

1. Secure Accessory

a. Place the accessory to be checkedin a vice or support fixture with the male spline in the vertical position.

2. Attach Accessory Spline Misalignment Gage

a. Screw the six furnished threaded bolts (3/8-24) into the base of the accessory spline misalignment gage from the top down.

b. Place accessory spline misalignment gage on accessory, rough center, and secure with six 3/8-24 furnished nuts.

3. Install Probe Tip

a. Select short probe tip.

b. Loosen set screw (4) and install short probe tip.

c. Retighten set screw (4).

4. Set Probe Tip

a. Loosen set screw (27) on knob (22) and allow the traversing rod to slide down until the probe tip is engaged in a spline groove about 1/16 in. from the top of the spline. Make sure indexing finger (20) is in Slot No. 1 adjacent to "white mark."

b. Lock set screw (27).

5. Adjust Probe Engagement in Spline Groove

a. Loosen cap screw (37) and rotate gage head until needle deflection is near the center of the meter.

b. Tighten cap screw (37).

c. Further adjust needle deflection, if necessary, by means of potentiometer on the amplifier.

d. Set the "range" selector to ±0.020 in. scale.

6. Misalignment Measurements—Radial Displacement

a. Turn on recorder.

b. Manually push the spline in toward its center and hold for several seconds to get the "in" measurement trace on the recorder.

c. Pull the spline back from its center and hold for several seconds to get the "out" measurement trace on the recorder.

d. Label the traces appropriately. For example, "1 in" and "1 out" represent Slot No. 1 "in" and "out" measurements.

e. Raise the traversing rod (23) so that the indexing finger (20) is free of the slot. Rotate the knob (22) and engage the indexing finger in the next slot. Allow the traversing rod to slide down to its measurement position.

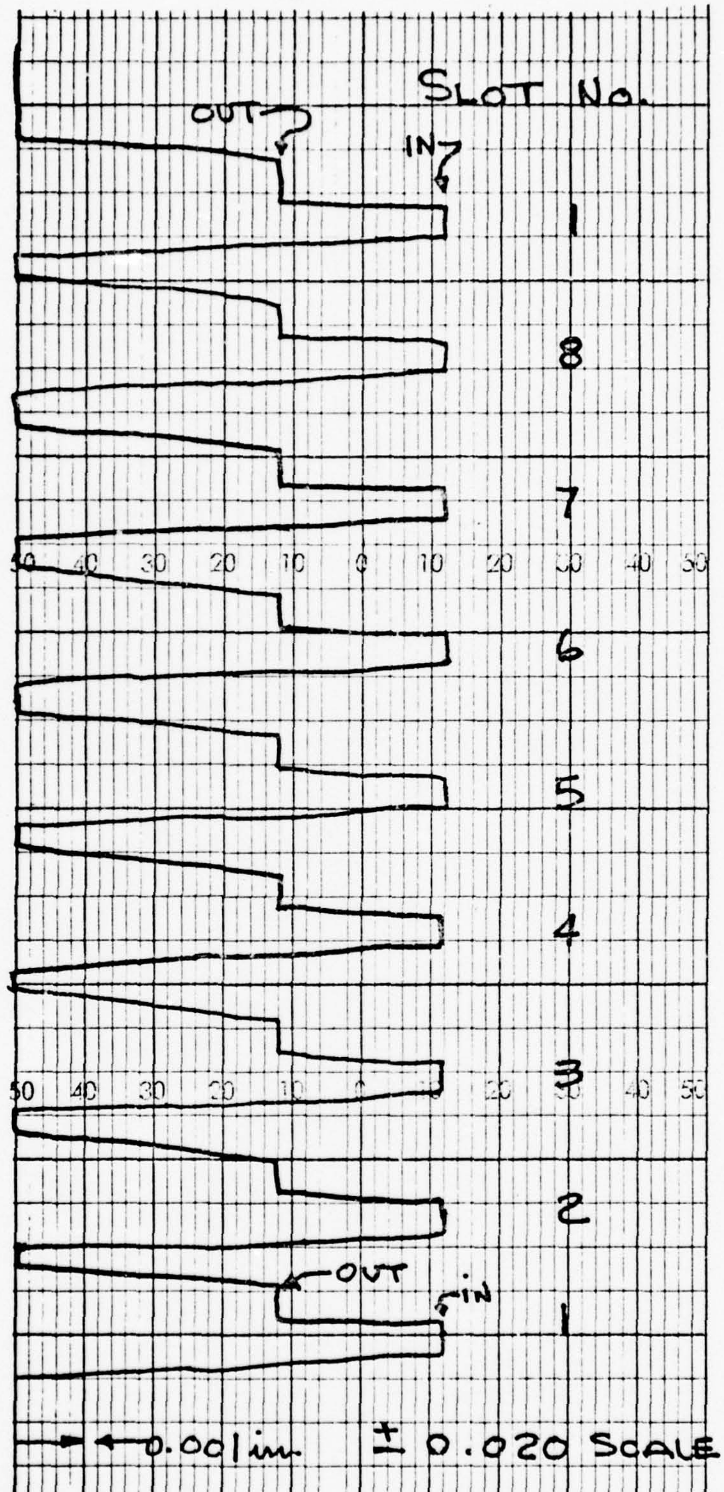
f. Repeat steps b through e until the indexing finger is back to its original position (Slot No. 1).

7. Typical Recorder Traces—Radial Displacement

In accordance with the Standards pertaining to accessory splines, the measurement of interest is the maximum radial displacement from the centerline defined by the pilot diameter. The determination of this measurement from the recorder traces is best shown by some examples.

Figure 15 shows the trace obtained for a radially-loose spline that has "no lateral misalignment" (the spline centerline coincides exactly with the centerline of the pilot diameter, i.e., concentric) and has a radial play of ±0.006 in. In this case, the maximum radial displacement is ±0.006 in.

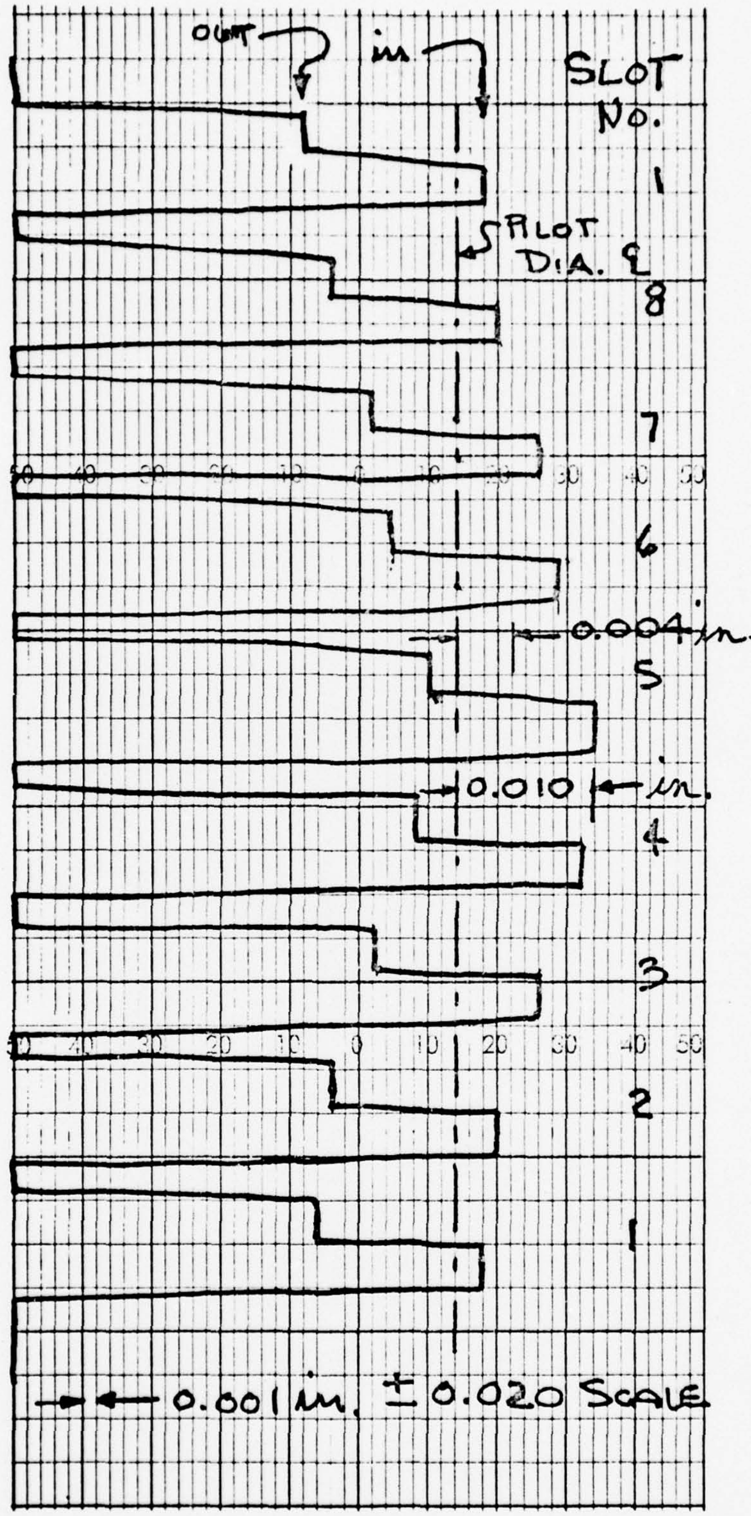
The more general case of a radially-loose spline "with lateral misalignment" is shown in Figure 16. The trace shown is for a spline that has a lateral misalignment of 0.004 in. (the centerline of the spline is offset from that of the pilot diameter by 0.004 in.) and radial play of ±0.006 in. In this case, the maximum radial displacement is the distance from the pilot diameter centerline which is lateral displacement 0.004 in. + radial play 0.006 in., or 0.010 in.



MISALIGNMENT

Concentric (Lateral) = 0
Radial Displacement = ± 0.006 in.

FIGURE 15. TRACE FOR SPLINE CONCENTRIC—
WITH RADIAL DISPLACEMENT



MISALIGNMENT

Concentric (Lateral) = 0.004 in.
Radial Displacement = ± 0.006 in.
Maximum Radial Displacement = 0.010 in.

FIGURE 16. TRACE FOR SPLINE NOT CONCENTRIC — WITH RADIAL DISPLACEMENT

8. Misalignment Measurements—Squareness

The measurement of the squareness or angular misalignment of a radially-loose spline is accomplished by performing steps 1-4, as described earlier, and then proceeding as follows:

a. Loosen set screw (27) and allow the traversing rod to slide down until the probe tip is at least 1/2 in. down the major diameter of the spline. (This depth should be as much as possible to provide the most accurate measurement of the angular misalignment.)

b. Displace the spline in a fixed position away from the probe tip.

c. Check to see that the probe tip is centrally located in the spline groove. Adjust if necessary.

d. Turn on the recorder and make necessary adjustments so that the recorder pen deflection corresponds to that of the needle on the meter.

e. Near the trace on the recorder paper, write the slot number and probe position (for example, "1B" means Slot No. 1 bottom position).

f. Raise the traversing rod (23) until the probe tip is near the top of the spline and hold for several seconds to get the top trace, i.e., "1T".

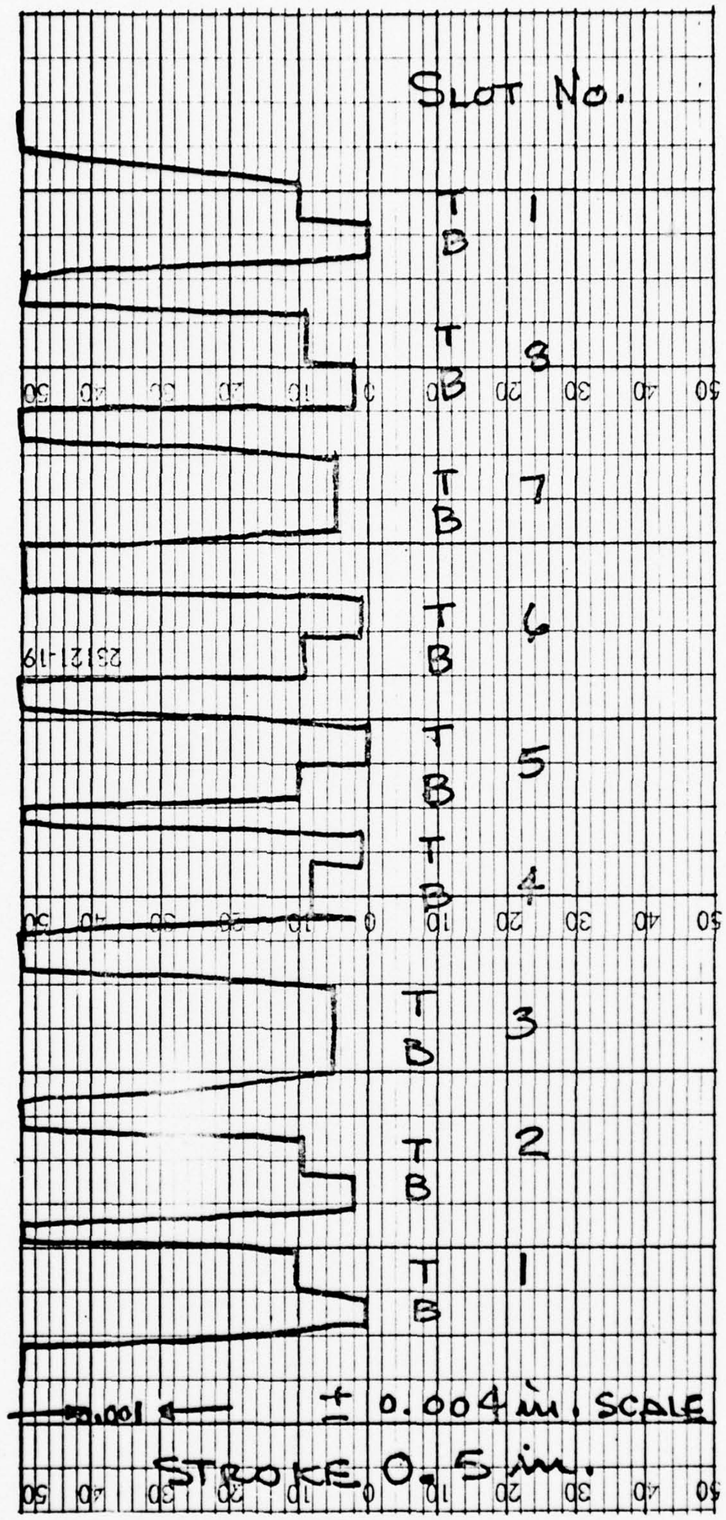
g. Repeat steps e and f until the indexing finger is back in its original position (Slot No. 1).

9. Typical Recorder Traces—Squareness

A typical angular misalignment measurement trace for a radially-loose external spline is shown in Figure 17. The amount of squareness or angular misalignment is calculated using the equation:

$$\text{Squareness} = \frac{\Delta TB_{max.}}{\text{Stroke}} = \frac{0.001 \text{ in.}}{0.5 \text{ in.}}$$

$$= 0.002 \text{ in./in.}$$



MISALIGNMENT

Concentric (Lateral) = 0
Squareness (Angular) = 0.002 in./in.

FIGURE 17. TRACE FOR SPLINE CONCENTRIC — SPLINE NOT SQUARE

10. Data Sheet

Figure 18 illustrates the data sheet used for the accessory spline misalignment measurements. The data sheet has been filled in to show the results of a test performed on a hydraulic pump. In Tests Nos. 1 and 2, the largest in-out radial displacement was found to be on Slot No. 1.

The squareness data in Test No. 3 indicated that $\Delta TB_{max.}$ was 0.0085 in. over a 0.7 in. stroke. The squareness (angular misalignment) is obtained by dividing the "stroke" into the "$\Delta TB_{max.}$" which is 0.012 in./in. in this case.

11. Pass-Fail Criteria

The pass-fail criteria for the "maximum radial displacement" and "squareness" specified by the AND and MS Standards for the 4.122 in. pilot diameter on an accessory is presented in Tables 4 and 5.

The AND Standards are somewhat ambiguous in specifying the exact maximum radial displacement (see Table 4, footnote a). It is believed that the intention of the AND Standards is to specify a maximum radial displace of ±0.006 in. as does the MS Standard.

The AND Standards are also vague in specifying the squareness (see Table 5, footnote a). If a maximum value of >0.005 in. is used for the 4.122 in. pilot diameter, then the rejection criteria is $>0.005 \div 4.122 = >0.0012$ in./in. for the AND Standards. The MS Standard specifies a maximum squareness of 0.003 in./in.

GEARBOX – OR – ACCESSORY SPLINE MISALIGNMENT

NARF North Island Bldg. 341 Date 10-23-75

Aircraft H-53 Engine ______ Pad for H-53 Remote Acc. G. B.

~~Gearbox~~/Accessory Hyd. Pump Pad Size 4.122 in.

Part No. 64WHO8001-1 Bolt Circle 5 in.

Serial B1-27 Operator M. Valtierra (SwRI)

Test / Scale	Pad No. / No. of Teeth	Radial Displacement — Pass < ±0.006, Fail >±0.006: Slot No.	ΔT, in. In-Out	Pass Fail	Squareness — Pass < 0.001, Fail > 0.001: Slot No.	ΔTB_{max} in.	Stroke in.	Amount in./in.	Amount deg.	Pass Fail
1 ±0.020	- / 16	1	0.041	Fail	-	-	-	-	-	-
2 ±0.020	- / 16	1	0.042	Fail	-	-	-	-	-	-
3 ±0.020	- / -	-	-	-	7	0.0085	0.7	0.012	0.69	Fail

Sketch -

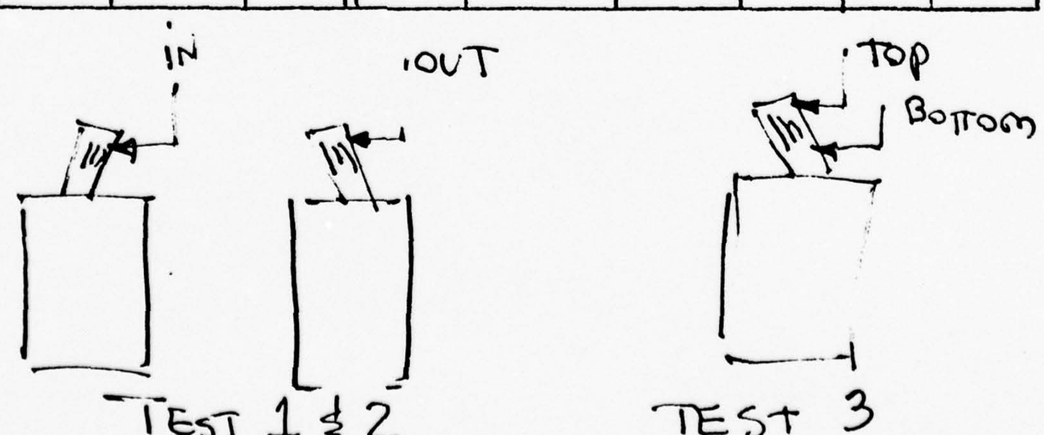


FIGURE 18. DATA SHEET FOR USE WITH ACCESSORY SPLINE MISALIGNMENT MEASUREMENTS

TABLE 4. PASS-FAIL CRITERIA
FOR MAXIMUM RADIAL DISPLACEMENT
OF RADIALLY-LOOSE EXTERNAL SPLINES

Standard	No. of Teeth	Specified Lateral Misalignment, in.	Rejection Criteria, in.
AND 10262	16, 24, or 26	$>\pm 0.006$[a]	$>\pm 0.006$
AND 10267	26	$>\pm 0.006$[a]	$>\pm 0.006$
MS 3332	16 or 24	$>\pm 0.006$[b]	>0.012 TIR

a. "Accessory shall be capable of satisfactory operation with the pitch diameter center of the drive spline displaced to a maximum 0.006 in. in any direction from the center defined by the 4.122 pilot diameter."

b. "The axis of the external spline pitch cylinder cannot be displaced more than 0.006 in. in any direction from the centerline axis of the pilot diameter."

TABLE 5. PASS-FAIL CRITERIA FOR SQUARENESS (ANGULAR MISALIGNMENT) OF RADIALLY-LOOSE EXTERNAL SPLINES

Standard	No. of Teeth	Specified Angular Misalignment, in. /in.	Rejection Criteria, in. /in.
AND 10262	16, 24, or 26	>0.005/4.122[a]	>0.0012
AND 10267	26	>0.005/4.122[a]	>0.0012
MS 3332	16 or 24	>0.003[b]	>0.0030

---

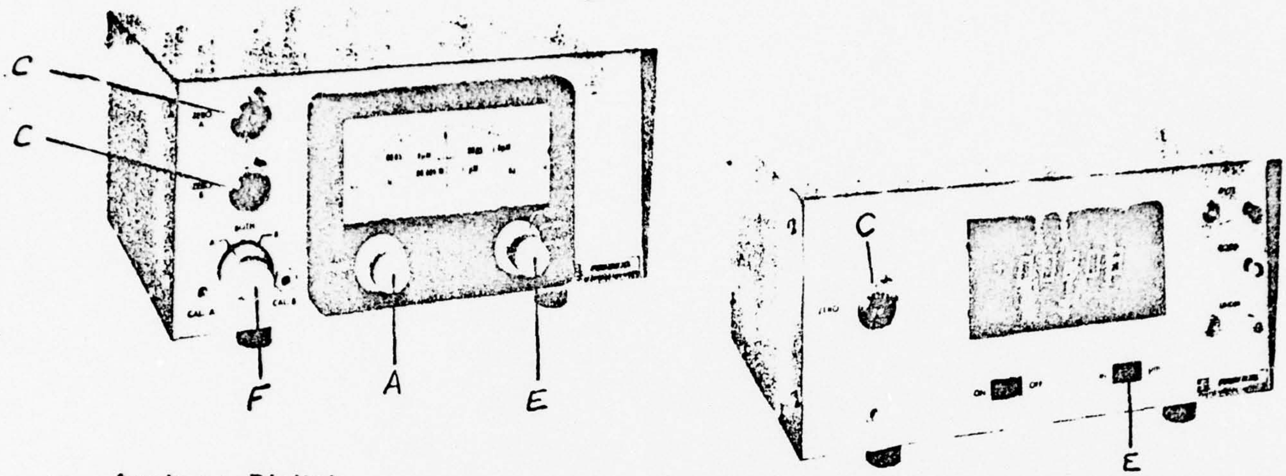
a. "Accessory shall be capable of satisfactory operation with the pitch diameter center of the drive spline out of square with mounting face 0.005 in. full indicator reading."

b. "The angular misalignment between these axes (axis of the spline pitch cylinder and the centerline established by the pilot diameter) shall not exceed 0.003 in. /in."

APPENDIX A

INSTRUCTION BOOKLETS

gaging data



Analog or Digital . . .

NEW, SERIES "432" ELECTRONIC AMPLIFIERS

Federal announces another advance in the development of high precision electronic gaging. The new Series "432" solid state electronic system provides a substantial increase in capability, accuracy and stability over other electronic gaging systems.

Eight new amplifier models are offered: analog or digital readout, single or dual input, optional "good", "over" and "under" signal lights.

All are completely solid state and fully compatible with Federal's versatile Multi-Choice electronic gaging system.

Like all other Federal electronic gaging components, these new "432" amplifiers are calibrated against ultra-precise standards, traceable to the National Standard.

FEATURES:

1. Choice of either analog or digital readout, single or dual gage head input.
2. English or metric scale values by switching for today's or tomorrow's needs.
3. Completely compatible with existing Federal Multi-Choice electronic gaging units without the need for recalibration.
4. Reliable, solid state circuitry assures high accuracy and stability.
5. Built-in "good", "over" and "under" signal lights optional on all models. Also, relay output option in addition to lights available as special application.
6. Heavier duty output to suit a wider variety of recording and display devices. Optional Binary Coded Decimal output available on digital readout models.
7. Analog models have patented "Click-Scale" dial which provides five magnifications, individually presented at the turn of a knob.
8. Built-in tilt-up stand for easier viewing of the meter or readout.
9. Plug-in circuit boards and integrated circuitry for easier serviceability.

Continued over

FEDERAL PRODUCTS CORPORATION, 1144 EDDY STREET, PROVIDENCE, RHODE ISLAND 02901 • 401-781-9300

ZERO RANGE ± .0025"

MODELS:

	INPUT	LIMIT LIGHTS	MODEL NUMBER	PRICE
Analog	Single	—	EAS-1460	$543.00
	Dual	—	EAS-1461	632.50
	Single	Yes	EAS-1462	653.00
	Dual	Yes	EAS-1463	742.00
Digital	Single	—	EAS-1464	975.00
	Dual	—	EAS-1465	1005.00
	Single	Yes	EAS-1466	1085.00
	Dual	Yes	EAS-1467	1215.00

SPECIFICATIONS:

Analog Models

	RANGE	MINIMUM GRADUATION	MAGNIFICATION
English	±.010"	.0005"	220X
	±.002"	.0001"	1100X
	±.001"	.00005"	2200X
	±.0002"	.00001"	11,000X
	±.0001"	.000005"	22,000X
Metric	±200um	10um	275X
	±40um	2um	1375X
	±20um	1um	2750X
	±4um	.2um	13,750X
	±2um	.1um	27,500X

Digital Models

	RANGE	MINIMUM DIGIT VALUE	DISPLAY
English	±.010"	.000010"	±.00000 to ±.01000
Metric	±200um	.1um	±0000.0 to ±0199.9

	ANALOG MODELS	DIGITAL MODELS
Repetition Accuracy	to within .000002" (.05um) or 1/10 scale division, whichever is greater	±1 digit
Calibration Accuracy	to within 4/5 scale division	±1 digit
Display	Analog meter, 5 English/Metric scales	5 Neon digits, ½" high, 7 bar display
Sampling Rate	Infinite	60 readings/second
Stability — Short Term	less than 0.01% change of gain over an 8 hour period	
Stability — Long Term	less than 0.1% change of gain over a 1 month period	
Thermal Drift	.01%/°F (.018%/°C)	
Power Requirements	10 watts (117V ±10%, 50-60 Hz)*	16 watts (117V ±10%, 50-60Hz)*
	*also, 220V ±10%, 50-60Hz, by switching internal jumpers	
Power Output	0.1 ohms @ 10 ma., ± 10V to a rear mounted connector	
Dimensions	10¾" x 8½" x 5¼" (27.3cm x 21.6cm x 13.3cm)	
Weight	14 pounds (6.35 kg)	

SUPPLEMENT

to

"MULTI-CHOICE" INSTRUCTIONS

FOR USE WITH

"432" SERIES AMPLIFIERS

The "432" series amplifiers, while different in appearance from the "232" series, is functionally almost the same. Therefore, with the exception of the following paragraphs, and the schematic drawings (enclosed for amplifier(s) ordered) the "232" Multi-Choice instructions apply. The attached Gaging Data sheet gives the general specifications for the "432" series.

EXCEPTIONS TO MULTI-CHOICE INSTRUCTIONS:

A. All "432" amplifiers are ENGLISH/METRIC MODELS. When calibrated in either system, calibration is automatically achieved in the other.

B. Four models are equipped with adjustable limits which cause RED, GREEN and YELLOW limit lights to function. Set limits as follows:

1. If maximum limit spread is within ±.0025", you can unplug the gage head(s) involved and set the meter to each limit with the ZERO knob. If limit spread exceeds ±.0025", you will need to displace the gage head contact enough so that the limit you are setting is within ZERO knob reach. Using appropriate method, set meter to read exact low tolerance limit value - say - .00025".

2. Use a small screwdriver to adjust the potentiometer at the left of the UNDER light until this light just goes out and the GOOD light goes on. Check setting by moving meter reading back towards 0 a little, then slowly towards -.00025". Just as meter passes .00025", UNDER light should come on. Fine tune limit pot if necessary.

3. Use ZERO knob to make meter read exact upper tolerance limit - say +.00025". Repeat procedure in Step 2 except use OVER limit pot to make OVER light go on just as meter reading exceeds +.00025".

C. CALIBRATION

On analog models, with power off, check alignment of hand with dial 0. If not exactly on 0, adjust screw in line with pivot point of hand until alignment is exactly on 0.

Turn power ON and allow the Amplifier to be in operation for a reasonable amount of time to be certain of complete stabilization.

SINGLE INPUT MODELS

1. Secure the Gage Head in a suitable fixture. Set the Amplifier Controls as follows. (See Data Sheet for identification of controls.)

   Mode Switch (E) ---------------------------------- IN

   Scale Selector Switch (A) (Analog meters only)--- Longest Range

   Polarity Switch (B) ---------------------------- "NORMAL"

   Electrical Zeroing Control (C) ---------------- No. 5 in the window

2. Select three grade AA gage blocks which differ in size by .010". Place the middle size block in position and adjust the position of gage head "B" mechanically so that the Meter reads as closely as possible to 0. Adjust Electrical Zeroing, if necesssry, to achieve precise alignment. Remove and reposition gage block to check for the proper repeat reading.
3. Substitute the +.010" gage block and observe any deviation from a plus .010" reading on the meter. If there is a deviation, use CAL screw to reduce the deviation by 1/2 its value.

4. Substitute the -.010" gage block and observe any deviation from a minus .010" reading. If there is one, use ZERO pot to reduce the deviation by 1/2 its value.
5. Repeat steps 3 and 4 until end-of-range errors are 1/2 graduation or less on analog meters or $\pm$ 1 count of least digit on digital meters.
6. Substitute the 0 gage block and observe any deviation from an exact 0 reading. If reading is more than 1/2 a graduation on analog meter, or more than $\pm$ one count of least digit on digital meter, reset meter to 0 with ZERO pot and repeat steps 3, 4 and this one.
7. Set the Polarity Switch (B) in the "REV." position and repeat steps 2 and 3, except do <u>not</u> adjust CAL crew or ZERO knob. Each reading should match the reading obtained in Step 3 within the calibration accuracy, but at the opposite ends of the scale.

DUAL INPUT MODELS

The checking and adjustment of these Amplifiers and the balancing of Gage Head outputs can be performed in one series of operations. It requires a fixturing setup that permits the contacts of both Gage Heads to engage the same AA gage block simultaneously. Point of contact should be as close together as possible.

1. Set the Amplifier controls as follows: (see Figures 17 and 18 for identification of controls.) Note: Make sure <u>both</u> Polarity Switches and <u>both</u> Electrical Zeroing Controls are set as stated.

Mode Switch (E) --------------------------- IN

Scale Selector Switch (A) (Analog meters only)- Longest Range

Polarity Switches near plug receptacles on back panel -- "NORMAL"

Electrical Zeroing Controls (C) -------------- No. 5 in the window

Head Selector Switch (F) --------------------- "B"

2. Select three grade AA gage blocks which differ in size by .010". Place the middle size block in position and adjust Gage Head "B" mechanicall so that the meter reads as closely as possible to 0. Adjust the Electrical Zeroing Control for Gage Head "B" if necessary, to achieve precise alignment. Remove the gage block and reinsert it to check for the proper repeat reading.

3. Substitute the +.010" gage block and observe any deviation from a plus .010" reading on the meter. If there is a deviation, use CAL B screw to reduce the deviation by 1/2 its value.

4. Substitute the -.010" gage block and observe any deviation from a minus .010" reading. If there is one, use ZERO B pot to reduce the deviation by 1/2 its value.

5. Repeat steps 3 and 4 until end-of-range errors are 1/2 graduation or less on analog meters or ± 1 count of least digit on digital meters.

6. Substitute the 0 gage block and observe any deviation from an exact 0 reading. If reading is more than 1/2 a graduation on analog meter, or more than ± one count of least digit on digital meter, reset meter to 0 with ZERO pot and repeat steps 3, 4 and this one.

7. Reverse B head polarity switch and repeat steps 2, 3 and 4, except do <u>not</u> make any adjustments. Readings should be same as they were at end of step 6 except with plus and minus at opposite sides of 0.

8. Place Gage Head "A" in position. Turn the Selector Switch to the "A" position and make adjustments as in Step 2.

9. Follow the same procedure as in Steps 2 through 7 except use CAL A and ZERO A pots.

10. Turn the Range Selector Switch to the shortest range and use the Electrical Zeroing Controls to set meter precisely to zero as the Head Selector Switch is placed alternately in the "A" and "B" positions.

11. <u>For balancing</u>, set one polarity switch to NORMAL and one to REVERSE. Then turn the Head Selector Switch to the "BOTH" position. The Scale Selector Switch should be set on the shortest range. Place the plus .010" gage block beneath the contacts of <u>both</u> gage heads. The meter should read within 5 graduations of zero for analog meters or ± 2 counts of least digit on digital meters. (10 graduations when using Gage Heads EHE-1045 or EHE-1054). A similar reading should be obtained with the minus .010" gage block in place. This indicates a balancing accuracy to within 0.25% at maximum displacement. (0.5% when using Gage Heads EHE-1045 or EHE-1054). If the balancing accuracy is not within 5 graduations on either side of zero, adjust either CAL A or CAL B as required.

12. Reverse setting of each polarity switch and repeat steps 8 and 9.

13. For tracking, place the middle size gage block beneath the contacts of both Gage Heads and recheck the zero reading. Adjust Electrical Zeroing, if necessary. Substitute as many intermediate sizes of grade AA gage blocks as desired to determine the response at various points throughout the ±.010" range.

The meter hand should not deviate more than 5 graduations on analog meters, or ± 2 counts on digital meters, indicating that tracking accuracy is correct. (10 graduations or ± 4 counts, when using Gage Heads EHE-1045 or EHE-1054). If the deviation is greater at any point, repeat the procedure to make certain that it has been accomplished correctly. If deviation persists, the Amplifier and Gage Heads should be returned to the Factory for service.

Note: The above procedure applies to Gage Heads having equal outputs.

D. For trouble shooting, and electronic study of "432" series amplifiers, consult appropriate schematic, (as listed below:)

Model #	Schematic
EAS-1460	EWD-1149
EAS-1461	EWD-1150
EAS-1462	EWD-1151
EAS-1463	EWD-1152
EAS-1464	EWD-1153
EAS-1465	EWD-1154
EAS-1466	EWD-1155
EAS-1467	EWD-1156

jbc

LEVER TYPE GAGE HEADS

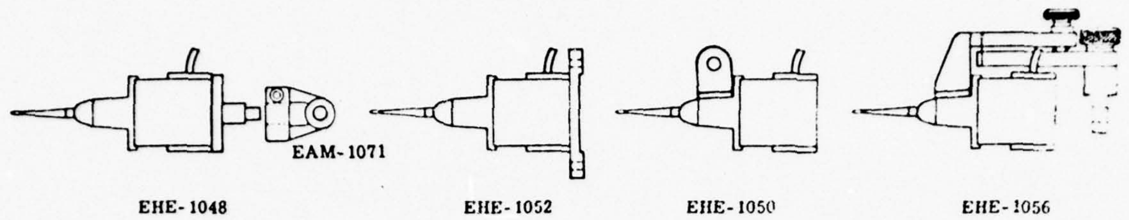


Figure 1

LEVER TYPE GAGE HEADS

Selecting The Holding Fixture

Because the Lever Type Gage Head has exceptionally light and uniform gage pressure, its use is not restricted to heavy type comparator fixtures. It is designed for use on any reasonably good gaging fixture that is conveniently available. See Figure 1 for gage heads and their integral mountings. Also, this light gaging pressure of approximately 2.5 grams permits leeway in the length of post and arm used in the gaging setup without running into inaccuracies due to deflection and lost motion. However, it is good gaging practice not to abuse this convenience.

For best accuracy in surface plate applications, it is good practice to move the work to and from the gaging unit, rather than moving the gaging unit to the work. Thus, you avoid the possibility of altering the gage head's position with respect to the reference surface.

Reversing Action

Gaging action of the Lever Type Gage Head can be reversed easily. Turning the Reversing Knob on the side of the gage head (see Figure 2) in a counter-clockwise direction makes the gaging contact sensitive to upward motion. Turning the knob counter-clockwise makes it sensitive to downward motion.

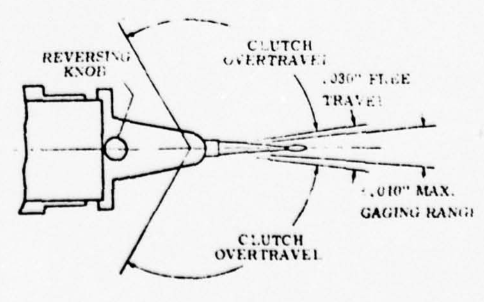


Figure 2

Repiacing Contact Points, Backs and Mountings

The Contact Point is made of hardened, chrome plated steel, and because gaging pressure is light, should last for a long period of time before becoming significantly worn. Replacement can be made easily, however, since the contact screws into the hub. When tightening the contact, do not use a wrench. . . finger pressure is sufficient. Excessive pressure may damage the precision pivots holding the hub. These pivots should never be disturbed. They are very carefully adjusted during assembly of the gage head to provide the exact fit required. Any attempt to adjust them will impair the action of the gage head.

CAUTION: In order to realize the maximum accuracy on the high magnification scales, the Gage Head Backs or Mountings should not be disturbed in the field. Consequently, special screws are used to insure permanent attachment. Every Gage Head with an eight-prong connector should be returned to the Factory if the Back or Mounting is to be changed.

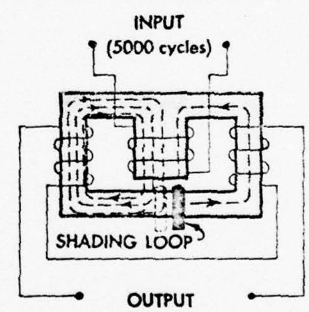


Figure 5

METHOD OF OPERATION
Lever Type Gage Heads

When the copper shading loop that is attached to the contact lever (or block) is in the center position (shown dotted in Figure 5), a 5,000 cycle current applied to the center coil sets up equal magnetic fields in the outer legs of the laminated core. Equal and opposite voltages are induced in the series connected outer coils, producing zero output. Movement of the shading loop to one side reduces the field in the nearest leg and increases the field in the other leg (as shown), making the voltages induced in the two coils unequal. The resulting output is the difference between the two induced voltages and it is in exact linear proportion to loop displacement. The gage head is mechanically arranged so that loop displacement is exactly equal to contact displacement.

SPECIFICATIONS
Lever Type Gage Heads

CONTACT	Hardened Steel, Chrome Plated
MAXIMUM GAGING RANGE	±.010"
PRETRAVEL	.005"
OVERTRAVEL	.005"
GAGING PRESSURE	Approximately 2.5 grams
CHANGE IN GAGING PRESSURE	Less than 0.1 gram per .001" of contact displacement

(All data based on Zero Control set at mid-range)

INSTRUCTION MANUAL

FOR

MODEL-500 POTENTIOMETER RECORDER

(Federal RE-100)

Instrument Corporation of America
1949 Greenspring Drive
Timonium, Maryland 21093
301-252-9220

TABLE OF CONTENTS

SECTION I

GENERAL DESCRIPTION

A. Introduction

The MODEL-500 Potentiometer Recorder is a self-balancing potentiometer recorder, used for indicating and recording d-c voltage inputs. The recorder can be adapted for use with different types of voltage sources by using the appropriate one of several available plug-in input units. This Manual describes the operation of the MODEL-500 with Type I, Type II, Type III, and Type IV input units. The Type I input unit is essentially a fixed span input unit where the span is specified by the customer. Type I input units are furnished for spans from 10 millivolts to 100 volts. There is a span adjustment on this input unit which allows adjustment of the specified span $\pm 10\%$. The zero adjustment for the Type I input unit can be specified by the customer to cover a limited range, to cover full scale of the recorder, or to be offset and adjustable up to 5 recorder spans. The Type II input unit has calibrated spans of 10, 20 and 50 millivolts. In addition there is an uncalibrated, continuously variable span control which increases these fixed spans by a factor of at least 2.5. The Type III input unit is provided with an attenuator for varying the recorder span from 10 millivolts to 50 volts calibrated. There is an uncalibrated span control on this input unit which will increase the calibrated spans by a minimum factor of 2.5. The Type III input unit also has a full-scale zero adjustment and up to 5 spans of zero suppression. The Type IV thermocouple input is furnished with plug-in range elements for matching the thermocouple output to the required recorder span. Specifications of the MODEL-500 with given input units are given in Section I. D. below.

B. Operating Principles

The MODEL-500 uses the proven null-balancing potentiometer principle to accurately measure input d-c millivolt signals. With this method the input signal is compared against a voltage derived from a precision linear potentiometer. A solid state chopper, driven at line frequency, switches between these two voltages, thus generating an a-c signal which is a measure of the difference between them. This

signal, at line frequency, is amplified in the high gain servo amplifier, then fed to the control winding of a two-phase servo motor. The reference winding of the servo motor is energized from the a-c line. The polarities and phase shifts in the system are so selected that the servo motor, which is mechanically coupled to the potentiometer, drives it to null the chopper output.

The indicating pointer and recording pen form an integral assembly which is also mechanically coupled to the servo motor output. Their horizontal position will therefore be a precise measure of the input d-c millivolt signal. The pointer position can be read from the indicating scale. The pen continuously provides a record of its position on the calibrated chart paper, which travels vertically at a predetermined rate with time.

For proper operation of the system, the precision potentiometer must be supplied with a stable, accurately known standard d-c voltage. In all input units, this voltage is supplied by a reference diode.

The MODEL-500 has a front access door containing a transparent panel through which the chart can be viewed. Opening of the door exposes the front panel of the input unit with its controls, switches, and fuse, the front of the chart drive mechanism, the indicating scale, pen, and pointer. Replacement of the ball point pen cartridge and chart paper can be accomplished without disassembly of the instrument. Removal of the input unit is accomplished by loosening the two screws holding the panel and pulling the unit forward.

At the back of the instrument are located the three binding posts for signal and ground connections, as well as the gain control. The power cord also enters the unit through the rear.

C. Common Mode Considerations

Because of the guarded input circuit, the inherent common mode rejection of the recorder is good. A 100 volt r.m.s. common mode signal will not seriously affect its operation. Despite this, common mode difficulties

are sometimes encountered, their cause being somewhat obscure, and the following suggestions are offered for solving them.

First, if common mode becomes troublesome below the 100 volt level, the real problem is that some fraction of the common mode voltage is being converted to input voltage. Fig. 1 shows one of the many ways this can come about. Common mode voltage forces a current to flow around the path shown, producing a voltage drop across the source resistance, R_S, which of course appears as a component of input voltage. Note that this effect operates regardless of how the shield is grounded. Several remedies are availabe. Fig. 2 shows a method which is usually successful and which has the merit of saving a wire. If the cable is long, however, current flowing in the loop indicated produces a voltage drop across the resistance of the shield, and this voltage again appears as a component of input voltage.

Fig. 3 shows a better method. Either end of the shield may be connected to the low side of the input, but not both. Occasionally, high frequencies are involved and it is necessary to use double shielded cable with the inner circuit wired as shown and the outer shield grounded at both ends.

Two further problems sometimes arise. The shielded cable may be part of some installation in which it is impossible to disconnect the shield from earth ground. This is not a genuine common mode difficulty because the combination of source resistance and cable capacity has already converted a fraction of the common mode voltage to input voltage by the time it reaches the recorder terminals. The simplest cure is to bypass the recorder input terminals with a capacitor. If this is unacceptable, the circuit of Fig. 4 may be tried, with C set equal to the internal stray of the recorder, about 300 pf, and R made equal to the source resistance. If the common mode voltage is large, the time constant RC for good rejection is critical, and one of the components, generally R, must be carefully adjusted.

The second problem is that of the "completely floating" source. Surprisingly large common mode voltages sometimes appear on such sources by capacity coupling to the power line. If permissible, bypass the low side of the input to the chassis with 1 UF. Otherwise, bypass the input

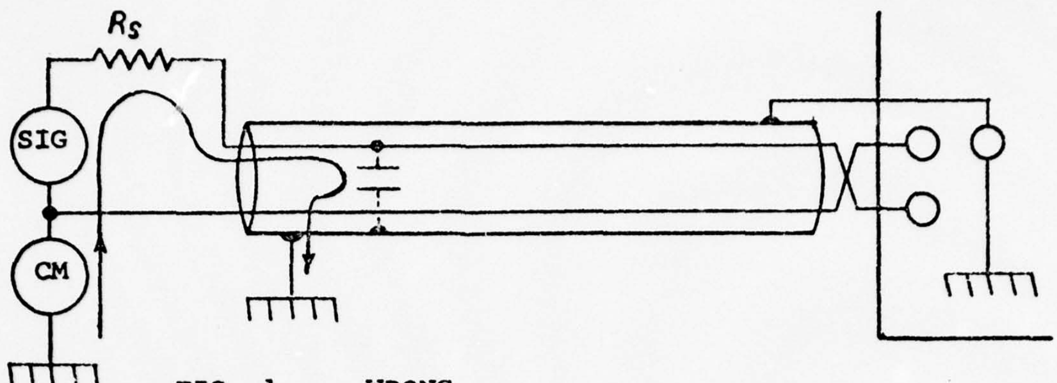


FIG. 1 <u>WRONG</u>

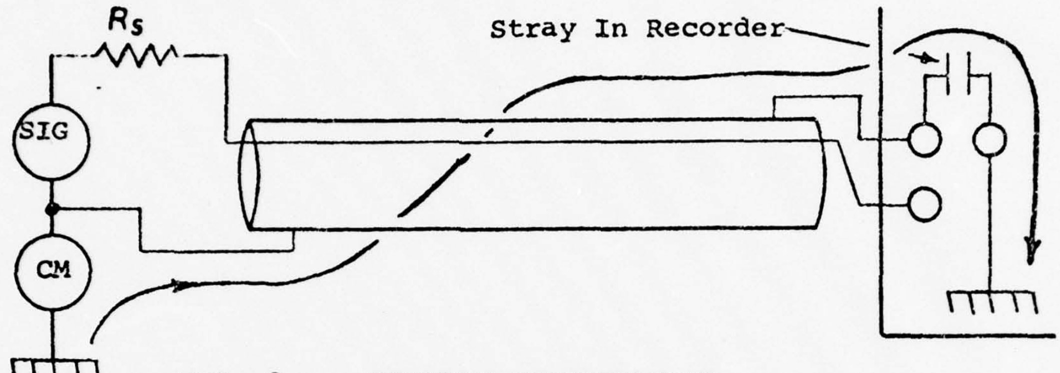


FIG. 2 USUALLY SATISFACTORY

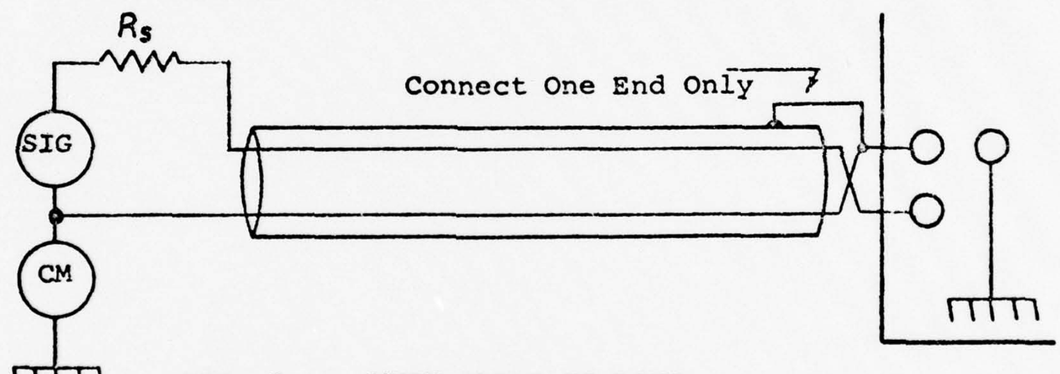


FIG. 3 WHEN CABLE IS LONG

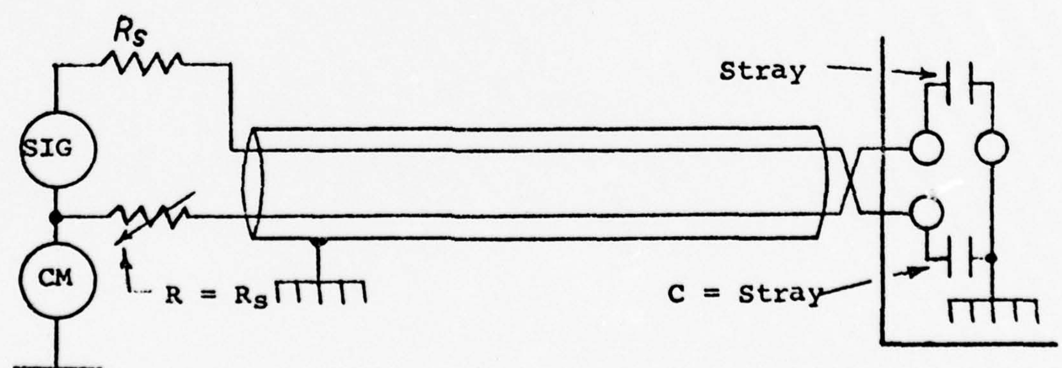


FIG. 4 IF SHIELD MUST BE GROUNDED

terminals. Power transformer stray in the recorder is phased to cancel if it is plugged into a correctly wired 3-wire receptable. If the receptacle is incorrectly wired, try reversing the power plug with a cheater and completing the ground connection with a jumper.

D. Equipment Supplied

Each MODEL-500 is furnished with the following supplies:

1. Basic Recorder, including input unit.

2. One roll of chart paper (installed).

3. One ball point pen.

4. One Instruction Manual.

Where inkless recording is desired rather than ink type, an inkless stylus and chart paper replace the standard pen and ink-type chart.

Panel-mounting units are supplied with all hardware required for mounting the recorder in a panel. The panel-mounted unit does not have rubber feet or carrying handle.

E. Specifications

The specifications for the MODEL-500 Potentiometer Recorder with Type I, Type II, Type III, and Type IV input units are given in the following tables.

Instrument Corporation of America 1949 Greenspring Drive, Timonium, Maryland 21093

MODEL 500, RECORDER SPECIFICATIONS

	Input Unit Type I	Input Unit Type II	Input Unit Type III	Input Unit Type IV
Span	Fixed, 10 millivolts to 100 volts, customer specified	Adjustable, 10 to 100 millivolts,	Adjustable, .01, .02, .05, .1, .2, .5, 1, 2, 5, 10, 20, 50 volts, calibrated. Up to 2½ times multiplier on these ranges with uncalibrated span control.	See Temperature Ranges * below.
Voltage Reference	Reference diode	Reference diode	Reference diode	Reference diode
Max. Source Resistance	100,000 ohms, 10 to 100 mv. One meg-ohm input resistance 100 mv to 100 v.	100,000 ohms	Recorder has 1 meg-ohm input resistance on all ranges, or by switch setting potentiometric input on .01,.02 and .05 volt ranges.	Thermocouple input
Zero Adjustment	Customer Specified	Full Scale	Full Scale to five spans zero suppression	$\pm$10% full scale
Full-Scale Response Time	3/4 second			
Accuracy	½% of span			

Plug in Range Element Reference Junction Compensation Provided	*Temperature Range °C	°F	Thermocouple Type
No. R-300	-20 to 300	0 to 600	I-C Type J
No. R-600	-20 to 600	0 to 1100	I-C Type J
No. R-1000	-20 to 1000	0 to 1800	I-C Type J
No. R-1200	-20 to 1200	0 to 2200	I-C Type K

Sensitivity	¼% of span
Input Circuit	Guarded input, floating, with separate chassis ground. 200 volts dc and 100 volts rms, 60 Hz common mode rejection.
Input Polarity	Positive signals cause left-to-right pen travel. Reversed polarity optional at no extra cost.
Recording Method	Ball point pen, or inkless on waxed paper.
Chart Width	4 inches calibrated.
Chart Length	60 feet with ink-type paper; 45 feet with waxed paper.
Chart Speeds:	
Drive Unit #1	¼,½,1,2,3,4, or 6 in/hr
Drive Unit #2	3,6,12,18,24,30,48, or 60 in/hr
Drive Unit #3	1,2,3,4,6,8,10, or 12 in/min
Drive Unit #4	2,4 8,12,20,32, or 48 in/min
Drive Unit #2S	3 and 60, 6 and 120, 12 and 240, 18 and 360, 24 and 480, 30 and 600, 48 and 960, 60 and 1200 in/hr
Case Dimensions:	
Portable	6 3/4" wide x 8 5/8" high x 10" deep
Panel Mount	6 3/4" wide x 8 5/8" high x 10" deep Panel size: 10½" high x 19"wide Panel cutout: 6 13/16" x 8 11/16"
Weight	17 pounds
Power Requirements	20 va, 115 v, 50-60 Hz, customer specified frequency

CHART PAPER

The following chart paper is available from stock. Special charts can be provided on special order.

Type	Divisions Across Chart	Line Spacing on Time Axis	Calibration
For Ink Recording -			
A	50 div. across 4"	1/10"	0-100
B	50 div. across 4"	1/4"	0-100
C	50 div. across 4"	1/3"	0-100
D	50 div. across 4"	1/4"	50-0-50
F	50 div. across 4"	1/4"	100-0
For Inkless Recording -			
R	50 div. across 4"	1/4"	0-100

SECTION II

INSTALLATION AND OPERATION

A. Inking System

The inking system employs a ball point pen. If the customer has specified inkless recording, a stylus is used for recording on waxed paper.

From time to time, it will be necessary to replace the ball point pen cartridge. In normal operation the ball point pen ink supply is sufficient to write approximately 5000 feet of line, thus affording an unusually long pen operating line.

The ball point pen operates at a pressure of about two ounces applied to the paper. This pressure is maintained by a leaf spring which is attached to the pen holder, and pressure is applied by means of an adjustable screw located on the pen carriage arm. It may be necessary to adjust the pen pressure after installation of a new pen cartridge.

To install a new pen cartridge, the following steps must be taken:

Lower the paper table of the chart drive unit to a horizontal position. Remove the pen holder by lifting the trunions clear of the pen carriage slots. Pull the pen holder clear of the recorder. Loosen the clamp screw retaining the pen cartridge in its holder, and remove the used pen cartridge. Insert the new pen cartridge and tighten the clamp screw. To adjust the pen pressure screw, the recorder must now be partially removed from its case in order to gain access to the screw. Loosen the captive screws located at the upper right and left sides looking at the front of the recorder. Slide the recorder forward about three inches. Insert the pen holder, and adjust the spring pressure screw to give a pen pressure on the paper not exceeding two ounces. The proper pressure may be determined by starting with zero pressure, rotating the pressure screw in one-quarter-turn increments, and advancing the paper under the pen, observing the pen line produced.

It will be found that upon reaching the proper pen pressure further turning of the pressure screw will result in no improvement in the pen line. Rotate the screw counter-clockwise to the first setting which produced a satisfactory pen line. Tighten the screw retaining nut. Insert the recorder into its case, and secure it by means of the captive screws.

B. Chart Paper Handling

1. Removal of Used Chart Paper Roll

To remove a used roll of chart paper, open the front access door of the recorder, exposing the front of the chart drive unit.

Raise the lever at the top left corner of the chart drive unit and gently lower the paper table. The used roll will be seen at the bottom of the paper table on the take-up spool. Lift the used roll free of the paper table and remove the paper roll from the take-up spool by sliding it off the unflanged end of the take-up spool. The take-up spool flange should be on the left as viewed from the front of the recorder.

2. Installation of New Chart Paper Roll

To install a new roll of chart paper, lower the paper table of the chart drive unit as described above. The chart roll is retained in a spring loaded shell which is spring loaded against the paper feed roller. Open the shell and insert the new chart roll. Unroll approximately 10 inches of paper, and engage the holes in the paper with the sprockets on each side of the paper feed roller.

Raise the paper table and snap it back into place. The guide clamps on each side of the mirrored platen must now be rotated outward to permit the paper to lie flat on the platen. Rotate the guide clamps by pulling forward and outward on the small buttons located near the top of the clamps. With these clamps retracted, lay the chart paper flat against the platen, then snap the clamps against the paper.

Again lower the paper table. Pass the free end of the chart paper around the lower, smaller roller. Form a "V" at the end of the chart paper by folding or cutting, and feed this "V" into the retaining spring on the take-up spool. Adjust the paper so that it feeds squarely onto the take-up spool. Rotate the take-up spool to take up the slack in the paper. Then raise the paper table and snap it back into place. To eliminate any remaining slack in the chart paper, manually advance the chart drive as described in Section II. B. 3.

3. Manual Advance of Chart Drive

The chart paper may be advanced manually to a new position whenever desired. To accomplish this, open the front access door and, with the thumb, push downward on the fine-toothed wheel at the upper right-hand side of the chart drive unit.

C. Power Connection

Power is applied to the instrument by means of the power cord which extends from the rear of the recorder. Observe the voltage and frequency requirements given on the recorder name plate. The power cord is of the three-wire type with two wires carrying the line voltage and the third wire carrying a ground.

It is important for proper recorder operation that the recorder case be grounded. This is accomplished automatically when the three-pronged power plug is inserted into a mating receptacle. However, if an adapter plug is used, the external lead of the adapter plug must be connected to a suitable ground such as a water pipe or electrical conduit.

D. Signal Connections

Figure 5 shows the terminal arrangement at the rear of the recorder. The two wires carrying the signal input to the recorder are connected to the red and black signal terminals located one above the other at the left-hand side of the rear panel. The positive lead should be connected to the red (lower) terminal, and the negative

lead to the black terminal which is directly above the red terminal. The metal terminal is chassis ground and is located directly above the GAIN control.

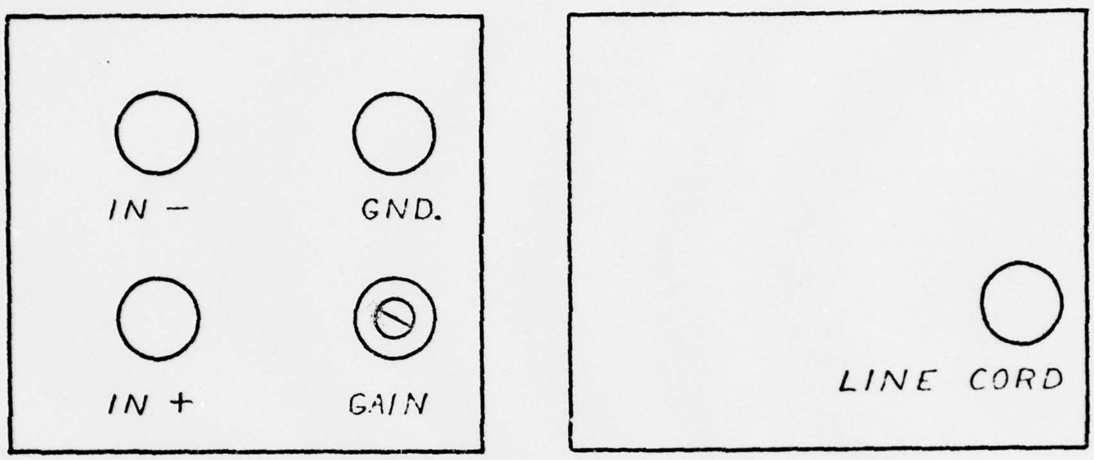


Figure 5 - Rear Terminal Arrangement

Left-to-right deflection of the pen will normally result from positive input signals connected as described above. However, in cases where a reversed-polarity instrument has been specified, the opposite direction of travel will result.

As mentioned in Section II. C. above, if grounding of the recorder is not accomplished by means of the power cord, a ground connection should be made to the ground terminal at the rear of the recorder located directly above the GAIN control. The input signals can be at a d-c level of as much as 200 volts positive or negative with respect to ground without impairing recorder performance. Signal leads at d-c potentials more than 200 volts from ground should not be connected to the recorder. If the input signal is completely floating with respect to ground, it is advisable to jumper the negative signal terminal to the ground terminal.

E. Power Switches and Fuse

Two power switches are located on the front panel of the input unit, behind the access door. The left-hand switch,

labeled POWER, energizes all the recorder circuits except the chart drive motor. After turning the POWER switch ON, allow 10 seconds for complete warm-up. The CHART switch, on the right-hand side of the panel, may then be turned ON.

For stand-by operation, the POWER switch may be left ON and the CHART switch OFF.

The input power to the recorder is fused with a Type AGX fuse of one ampere rating. This fuse is located in a fuse-holder mounted on the front panel of the input unit between the POWER and CHART switches. An exact replacement should be employed when required.

F. Recorder Adjustment and Calibration

All controls except the GAIN control are located on the front panel of the input unit, and are reached by opening the front access door of the recorder. The GAIN control is located on the rear panel of the instrument, directly below the metal ground terminal. Adjustment of all controls is accomplished as described below.

1. Setting the GAIN Control

The GAIN control can best be set by removing the recorder from its case. Switch the recorder on. Rotate the GAIN control fully counterclockwise, reducing the recorder GAIN to a minimum. Check the dead band as follows. Manually move the pen a few per cent in one direction by turning the motor drive pulley. Allow the pen to rotate slowly to its rest position and note this position. Repeat this procedure in the reverse direction. The dead band is the difference between the two rest positions expressed as a percentage of the total span. It should not exceed ½%. If the dead band exceeds this amount, rotate the GAIN control clockwise a quarter turn and repeat the dead band measurement. Continue to increase the recorder GAIN in the above manner until the dead band is within specifications. If the GAIN is increased to zero, it will be evident by noisy pen motion of up to 1% or so. The recorder should be supplied with a GAIN adjustment which eliminates any evidence of pen motion due to excessive noise.

2. Setting the ZERO Control

The ZERO control is used to place the recording pen at the desired zero position. The signal voltage input to the recorder should be zero when this adjustment is made except with the Type III input unit which has zero suppression incorporated into the ZERO control. Refer to the Model-500 Recorder specifications for the range of ZERO adjustment available on the various input unit types.

Setting the ZERO control is straightforward with all input unit types. With the Type III unit, up to five full spans of ZERO suppression are available. This allows the user to record for example the top ten millivolts of a 60 millivolt signal. The five spans of ZERO suppression are available on all recorder spans.

3. Setting the SPAN Control

The Model-500 is factory calibrated to a desired span prior to shipment. Should the customer, however, wish to check or adjust the span setting, the following procedure can be used.

The Type I input unit has a fixed span, the value of which is customer specified. Zero the recorder as described above, and connect to the recorder input terminals an accurate voltage source such as a Leeds and Northrup Type 8690 Millivolt Potentiometer. Adjust the controls of this potentiometer to deliver the millivolt value which has been furnished by the factory. The recorder pen should go to full scale. If it doesn't, adjust the SPAN control on the input panel until the pen reads full scale.

The Model-500 recorders with Type II and Type III input units incorporate a 10-20-50 millivolt switch. Check and set the span on these instruments using the following procedure.

Set the switch to 50 millivolts. Apply a 50 millivolt signal and adjust zero control to set pen on right hand edge. Set input voltage to zero and adjust span trimmer R34 to set pen on left hand edge. Set switch to 10 millivolts and adjust zero to left hand edge. Check 50 millivolt and 10 millivolt ranges and repeat this procedure if necessary. Check 20 millivolt range.

Setting the SPAN control on the Type IV input unit is described below.

G. Thermocouple Input Chassis Type IV

The Type IV input unit is designed for use with thermocouples for the direct measurement and recording of temperature. This input unit is interchangeable with other Model-500 input units, being designed for plug-in installation. Thermocouple cold junction compensation is provided so that ambient temperature changes at the thermocouple reference junction are automatically compensated.

Various temperature ranges are provided for by means of interchangeable range elements which plug into the Type IV input unit. These range elements are precision wire wound resistor networks which determine the millivolt input level required for full-span recorder deflection, and incorporate a resistance divider to match the cold junction compensation signal to the characteristic of the thermocouple in use. The range elements presently available, along with the corresponding temperature ranges, are listed in the following table. Other temperature ranges can be provided on special order.

The thermocouple reference junction is made at the recorder terminals, the thermocouple wire being connected directly to these terminals. The input terminals are located at the rear of the recorder and are vertically in line with one another. The positive thermocouple lead is connected to the red terminal, and the negative thermocouple lead is connected to the black terminal. The metal terminal is chassis ground, provision having been made for a floating input.

1. Installation and Operation

Make certain that the input unit has the proper range element installed for the desired temperature span.

The ZERO control adjusts the recorder to a reference temperature, e.g., 0^{o}C or 32^{o}F, and the SPAN control adjusts the span of the recorder.

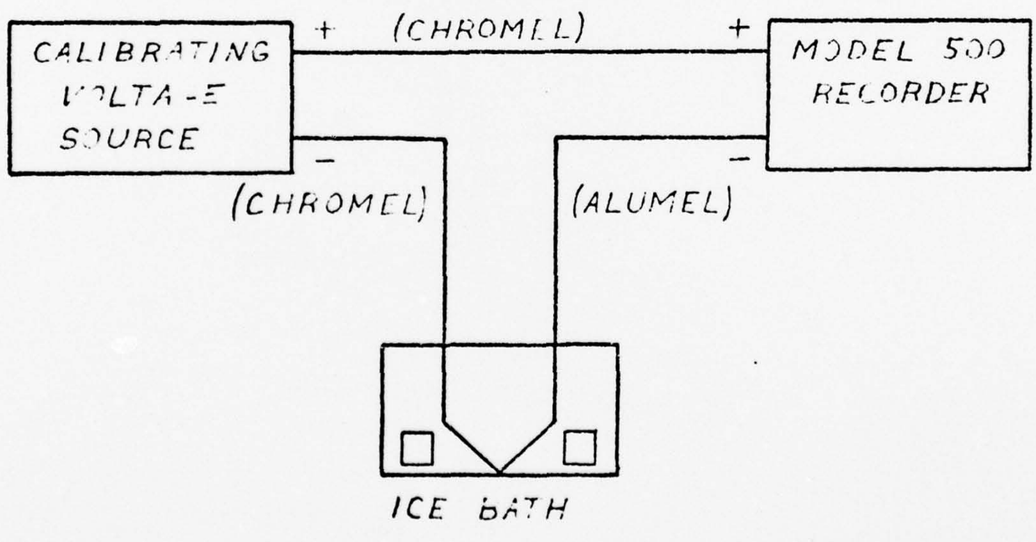
For operation of the Model-500 with the Type IV input unit, it is only necessary to turn the recorder on, having installed the input unit, connected the thermocouple to the

input terminals, and having placed the thermocouple hot junction at the temperature source. The Type IV input unit has been zeroed to a reference temperature and calibrated before shipment. Should it be necessary to check these adjustments, the following procedure can be carried out.

2. Calibration

The Model-500 can be calibrated with the Type IV input unit by making connections as shown below. A suitable calibration source, such as a Leeds and Northrup Millivolt Potentiometer Type 8690, is required along with the proper thermocouple wire and a small amount of ice. Turn the recorder on and place the thermocouple in the ice bath. After approximately three minutes, adjust the ZERO control to give a recorder reading of 0 degrees C or 32 degrees F with a calibration source voltage of zero. Set the calibration source voltage to the value obtained from the table below for the range element in use. This is the voltage which gives full span recorder deflection. Adjust the SPAN control to give full span deflection.

Once the ZERO and SPAN controls have been adjusted, range elements for other temperature ranges can be plugged in without the need for readjusting these controls.



Calibration with Type IV Input Unit

H. Input Unit Replacement

To remove the input unit from the recorder, the recorder must be removed from the case. Then, remove the two screws at the upper corners of the input unit panel. With these screws removed, the input unit is free to unplug from its mating connector, and this can be accomplished by pulling at the edges of the input unit panel.

To install an input unit, the reverse of the above procedure is employed. Insert the unit gently until its rear receptacle is felt to engage properly with the mating plug inside the recorder. Then push the unit in, firmly seating it. The two front panel screws should then be installed to hold the input unit in place.

Make certain that the covers of the input unit are in place before installation. The metallized side of the cover should be inside, with the insulating surface outside.

I. Chart Speed Changes

A number of different chart speeds may be obtained with each chart drive unit by means of speed change gears. These gears are always furnished in sets of two, and a chart speed change is effected by installing both gears of a set in place of the two corresponding gears already in place in the chart drive unit.

To make a chart speed change, the front access door of the recorder is opened, exposing the front of the chart drive unit. To expose the gearing, raise the lever at the top left corner of the chart drive unit and lower the paper table to a horizontal position. Remove the paper table. Two knurled wheels will be observed facing the front of the drive unit and centrally located within it. These wheels hold in place the two gears which are to be replaced for speed change. Unscrew and remove the two knurled wheels, then pull off the two gears located behind them. Install in their places the two gears for the new speed which is desired. Be certain that the gear marked "A" is installed on the "A" shaft, and the gear marked "G" on the "G" shaft. It is possible that one of the two gears, if it is a small one, will not be marked, but at least one gear of the set of two will be marked to specify its proper shaft.

MODEL-500 TYPE IV INPUT UNIT RANGE ELEMENTS FOR TEMPERATURE RECORDING

Range Element	Temperature Range		Calibration Voltage-MV		Thermocouple
	°C	°F	From 0°C	From 32°F	
R-300	-20° to 300°	0° to 600°	16.33	17.18	I-C type J
R-600	-20° to 600°	0° to 1100°	33.11	32.72	I-C type J
R-1000	-20° to 1000°	0° to 1800°	57.70	56.64	I-C type J
R-1200	-20° to 1200°	0° to 2200°	48.89	49.05	C-A type K

I-C (Iron Constantan)
C-A (Chromel-alumel)

It is important that the gears be pushed all the way forward on their respective shafts. Be sure that the slotted hub of each gear is positioned on its shaft so that the shaft key fits into the slot. The gear can then be pushed forward as far as possible until the end of the slot hits the key, preventing further travel. After both gears are in place, reinstall the knurled wheels, tightening them securely. Replace the paper table and the recorder is again ready for operation.

SECTION III

MAINTENACNE

A. Lubrication

Lubrication of the Model-500 should be accomplished as shown below. Do not lubricate the rod on which the cylindrical pen-carriage bearing travels. This rod and bearing should never be lubricated, but should be wiped clean periodically. If residue accumulates on the rod, remove it with crocus cloth.

LUBRICATION SCHEDULE

Part	Lubricant	Lubrication Period
Idler Pulleys (pen drive assembly)	Light machine oil	Every 6 months
Accessible Shaft Bearings and friction points in chart drive mechanism	Watch oil, Elgin M-56b or equal	Every 6 months
Balancing Motor	SAE 20 or 30	Every 6 months

SECTION IV

LIMIT SWITCHES

Adjustable limit switches are provided which can be used for controlling a process or for sounding an alarm when these switches are actuated by the recorder pen motion. These switches are snap action, cam operated components which have an accuracy in setability and operation of approximately 0.25% of full scale.

In the discussion below the following definitions are used:

1. Switch actuates when cam moves switch actuator toward front of recorder.
2. Normally closed and normally open refer to switch position when switch is not actuated.
3. C = Common (switch arm)
4. NC = Contact normally closed to common
5. NO = Contact normally open to common

The lower limit switch is actuated when the recorder pen travels down scale. The lower limit switch can be set, by adjusting the position of the cam which actuates the switch, to actuate at any point from 0 to 90% of full scale.

The upper limit switch is actuated when the recorder pen travels up scale. The upper limit switch can be set, by adjusting the position of the cam which actuates the switch, to actuate at any point from 100% to 10% of full scale.

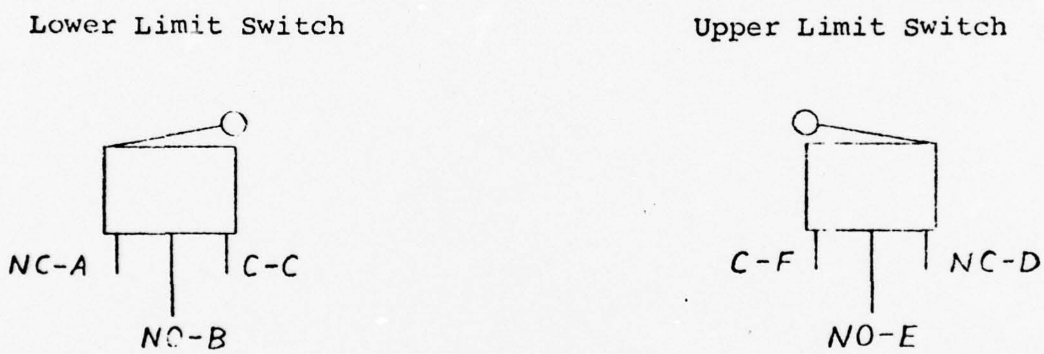
To set the lower limit, rotate the motor pulley to which the switch cams are attached, until the recorder pen is at the position on the chart paper at which the lower limit switch is desired to actuate. Loosen the thumb screw which fixes the lower cam position (long screw). Rotate the lower cam clockwise until the lower limit switch just actuates (a switch click is heard). Tighten the long thumb screw to fix the lower cam position. Rotate the motor pulley back and forth about the set point, observing the switch click on and off and checking the set point on the chart paper.

To set the upper limit, rotate the motor pulley until the recorder pen is at the position on the chart paper at

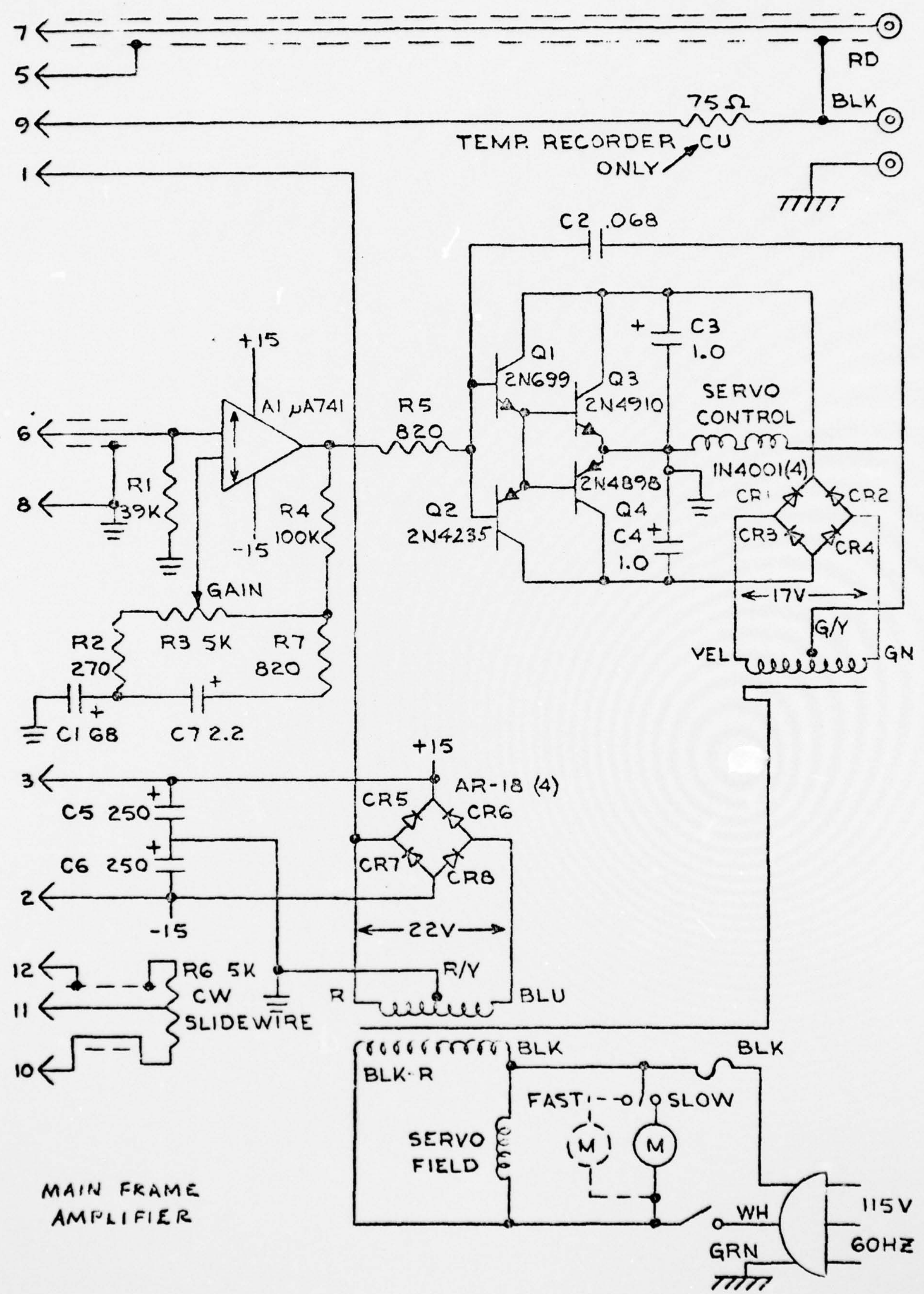
which the upper limit switch is desired to actuate. Loosen the thumb screw which fixes the upper cam position (short screw). Rotate the upper cam counterclockwise until the upper switch just actuates (a switch click is heard). Tighten the short thumb screw to fix the upper cam position. Rotate the motor pulley back and forth about the set point, observing the switch click on and off checking the set point on the recorder chart paper.

The current capacity of the limit switches and their wiring is 5.0 amperes, inductive or resistive.

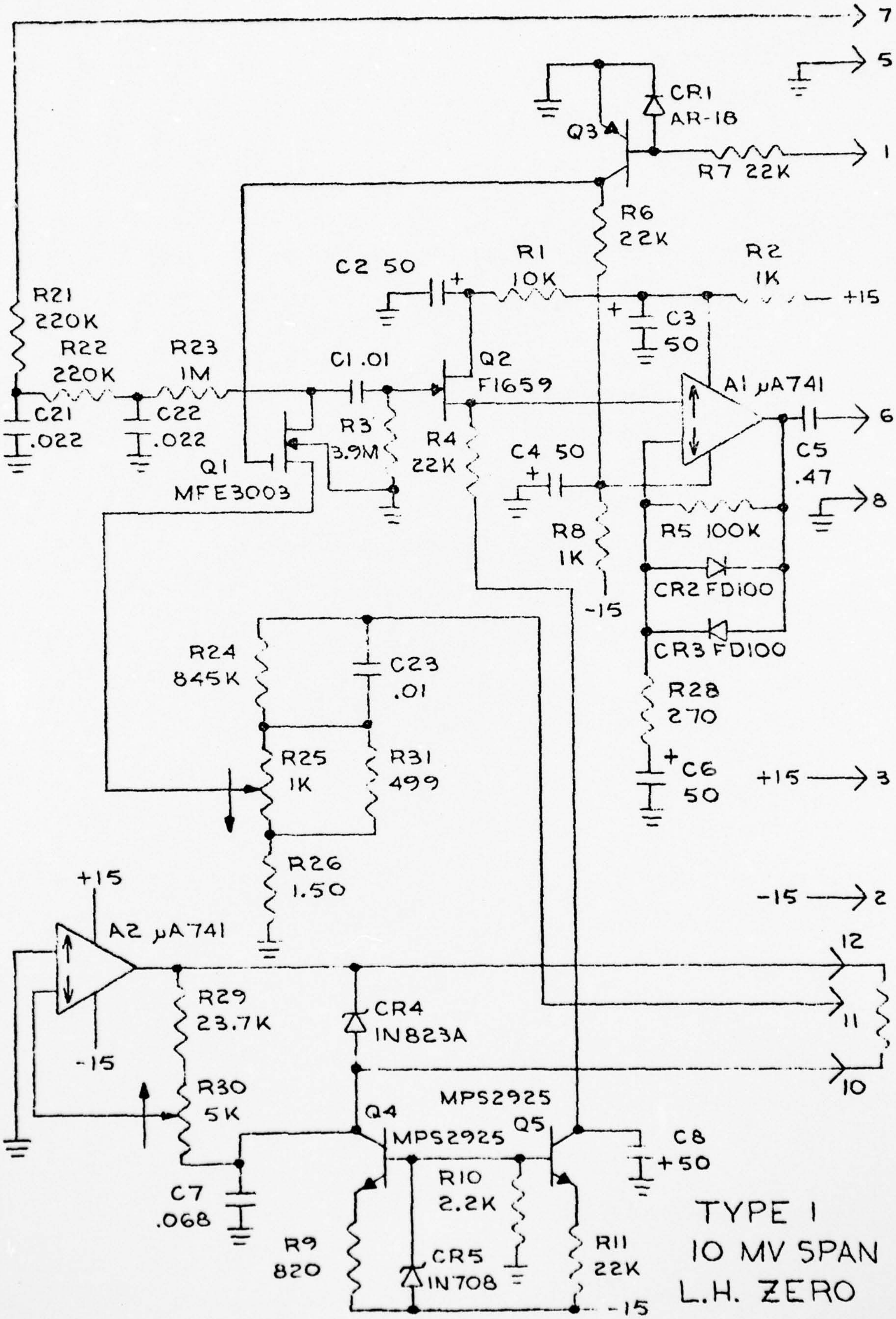
The following diagram shows the physical location of the limit switches and their wiring to the connector at the rear of the recorder.



View of limit switches looking down and toward the rear of recorder. Dash letters refer to pins on connector to which switch contacts wire. For example, NC-A is the normally closed contact on the lower limit switch wiring to pin A on the connector at the rear of the recorder.



MAIN FRAME
AMPLIFIER


7
5
1
6
8
3
2
12
11
10
CR1
AR-18
Q3
R7 22K
R6
22K
C2 50
R1
10K
R2
1K
+15
C3
50
R21
220K
R22
220K
R23
1M
C1 .01
Q2
F1659
A1 µA741
C21
.022
C22
.022
R3
3.9M
R4
22K
C4 50
C5
.47
Q1
MFE3003
R8
1K
-15
R5 100K
CR2 FD100
CR3 FD100
R24
845K
C23
.01
R28
270
R25
1K
R31
499
C6
50
+15
R26
1.50
-15
+15
A2 µA741
R29
23.7K
CR4
1N823A
-15
R30
5K
Q4
MPS2925
MPS2925
Q5
C8
+50
C7
.068
R10
2.2K
R9
820
CR5
1N708
R11
22K
-15
TYPE I
10 MV SPAN
L.H. ZERO

APPENDIX B

SOME DESIGN CONSIDERATIONS

1. Error Due to Angular Displacement of Probe Tip from Plane of Maximum Misalignment

The most crucial part of the interpretation of the recorded measurements is the application of the criteria to show "conformance" or "nonconformance" with the specified allowable misalignments. A factor which must be recognized in doing this is the fact that because of the space between the indexing collar slots and, also the space between adjacent spline grooves, the probe does not always traverse those portions of the major diameter cylinder corresponding to the maximum lateral misalignment, see Figure B-1. Using the nomenclature given in Figure B-1, it is apparent that if the probe tip were to traverse opposing spline grooves in the plane of misalignment, the misalignment as represented by TIR is as follows:

$$TIR = R_{ga} - R_{gb}$$

$$TIR = R_s + \ell - (R_s - \ell) = 2\ell$$

However, when the probe tip is displaced some angle ϕ from the plane of maximum misalignment

$$R_{ga} = R_s \cos \beta + \ell \cos \Phi$$

$$\text{where } \cos \beta = \frac{\sqrt{R_s^2 - \ell^2 \sin^2 \Phi}}{R_s}$$

For all practical purposes, $\cos \beta = 1$. Thus

$$R_{ga} = R_s + \ell \cos \Phi$$

$$R_{gb} = R_s - \ell \cos \Phi$$

$$\text{Measured TIR} = R_s + \ell \cos \Phi - (R_s - \ell \cos \Phi)$$

$$= 2\ell \cos \Phi$$

$$\text{Error (E)} = 2\ell (1 - \cos \Phi)$$

The application of the equation is best shown by an example.

When using the 8-slot indexing collar, the point of maximum misalignment can be as much as 22.5° displaced from the slot position. If this should occur, the measured TIR can be in error by the amount given by the equation below:

$$\text{Error (E)} = 2\ell [1 - \cos 22.5]$$

$$= 0.1522\, \ell$$

APPENDIX B

SOME DESIGN CONSIDERATIONS

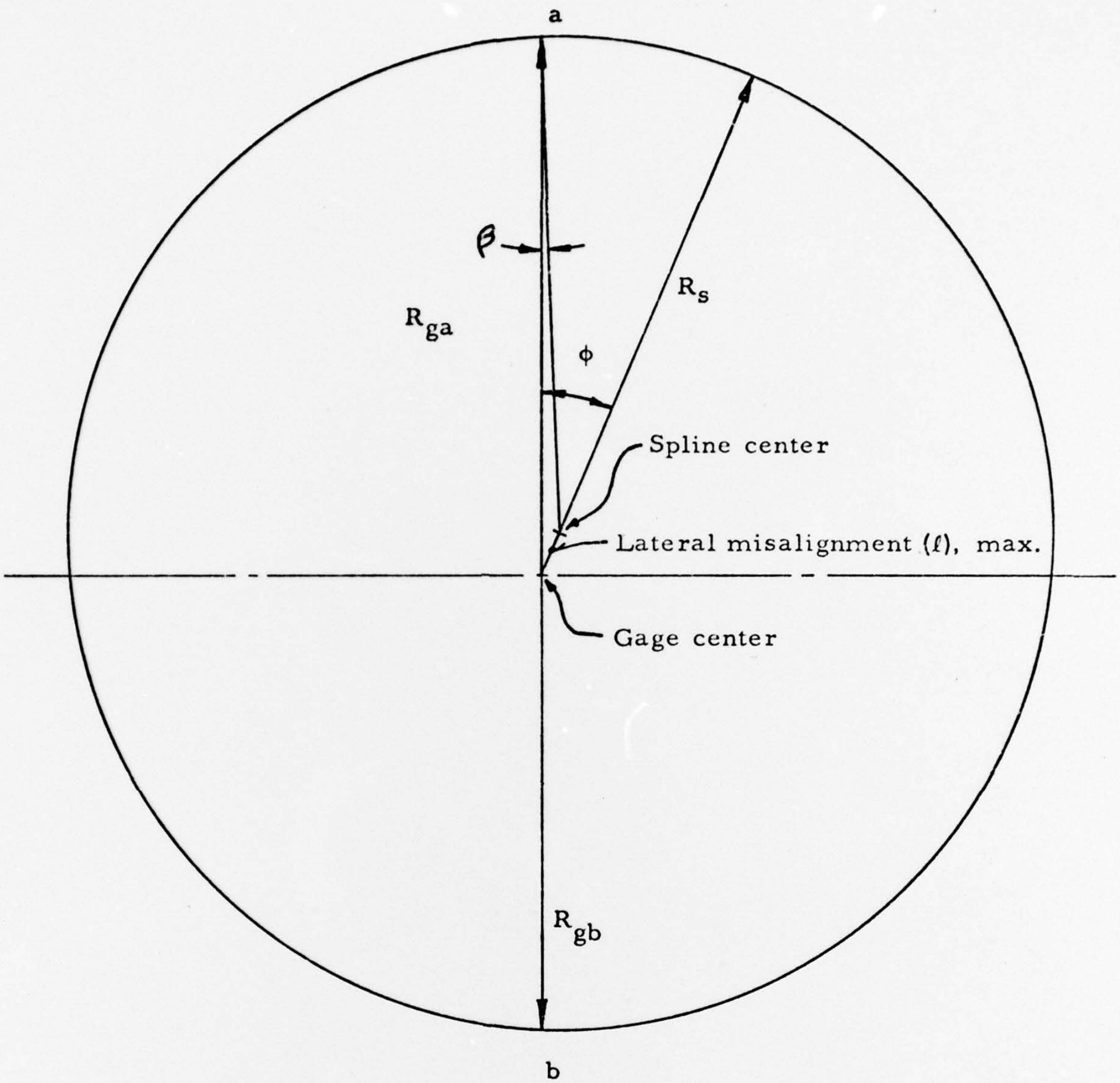


FIGURE B-1. ERROR DUE TO ANGULAR DISPLACEMENT OF PROBE TIP FROM DIRECTION OF MAXIMUM MISALIGNMENT

where ℓ is the lateral misalignment. In the case of a spline that is misaligned by 0.003 in. (0.006 in. TIR), this amounts to an error of 0.00046 in., thus the measured TIR would be only 0.00554 in. Therefore, when using the 8-slot collar, a measured TIR of 0.00554 in. or less would indicate compliance with the maximum specified lateral misalignment. A measured TIR in excess of 0.006 in. would clearly constitute noncompliance with the specified misalignment. Measured misalignments ranging from 0.00554 in. to 0.006 in. would indicate possible excessive misalignment, but additional measurements are required to show this conclusively. These additional measurements can be made by rotating the indexing collar so that the probe is moved over one tooth. In the case of a 24-tooth spline, this amounts to moving the probe 15°, and the maximum point of misalignment can now be no more than 15° from the probe. Now the maximum error in readings will be

$$E = 2[1 - \cos 15°]$$

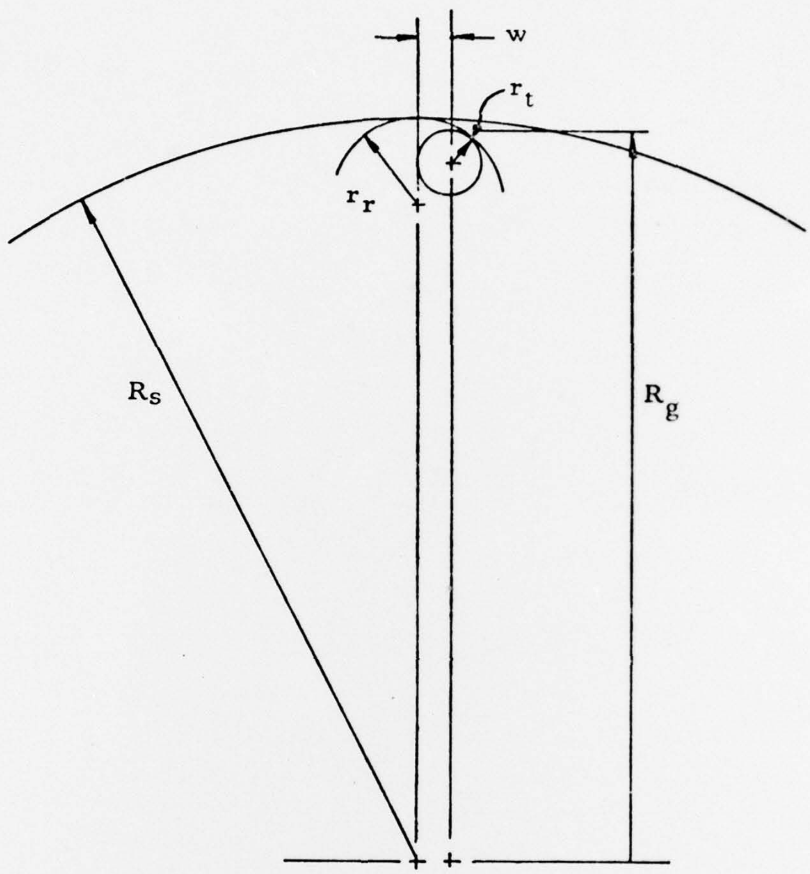
$$= 0.06815\ell$$

In the case of a spline laterally misaligned by 0.003 in. (0.006 in. TIR), the measured TIR would then be 0.00580 in. Therefore, a measured TIR of 0.00580 in. or less indicates compliance, while measurements between 0.00580 in. and 0.006 in. are uncertain. By moving the probe over one more tooth, the criterion for compliance becomes 0.00595 in. which is for practical purposes 0.006 in. A similar situation will exist with regard to angular misalignment.

2. Error Due to Tip Centering and Tooth Spacing

There is one other source of induced error in the measurement of spline misalignment. This error can result from slight errors in centering of the probe tip in the spline grrove and also from errors in tooth spacing. This type of error can best be understood by examination of Figure B-2 and the equations which will be developed.

Figure B-2 represents the situation where the probe tip is displaced a small amount (w) from the center of the spline groove. For convenience the spline groove radiused root is enlarged in Figure B-3, which also contains the equations needed to calculate the induced error (h). The equations were used to calculate h for three different displacements (w) and the results are plotted in Figure B-4. The plot shows that the errors due to tip displacement can be minimized by using tips with radii as small as possible (large r_r - r_r). Consequently, a relatively pointed probe tip has been designed for use with the gearbox and accessory spline misalignment gages.



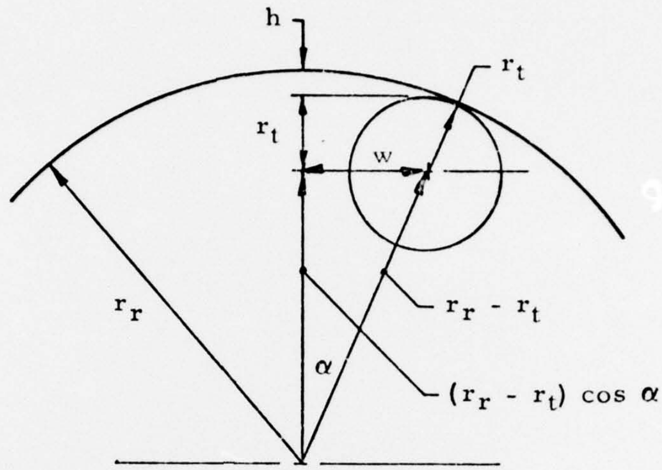
r_t = tip radius

r_r = root radius

R_s = spline major radius

R_g = gage radius

FIGURE B-2. PROBE TIP DISPLACED IN SPLINE GROOVE



$$\alpha = \arcsin \frac{w}{r_r - r_t}$$

$$h = r_r - r_t - (r_r - r_t) \cos \alpha$$

$$= (r_r - r_t)(1 - \cos \alpha)$$

$$= (r_r - r_t) \left[1 - \frac{\sqrt{(r_r - r_t)^2 - w^2}}{r_r - r_t} \right]$$

$$= (r_r - r_t) - \sqrt{(r_r - r_t)^2 - w^2}$$

FIGURE B-3. ENLARGED SPLINE GROOVE

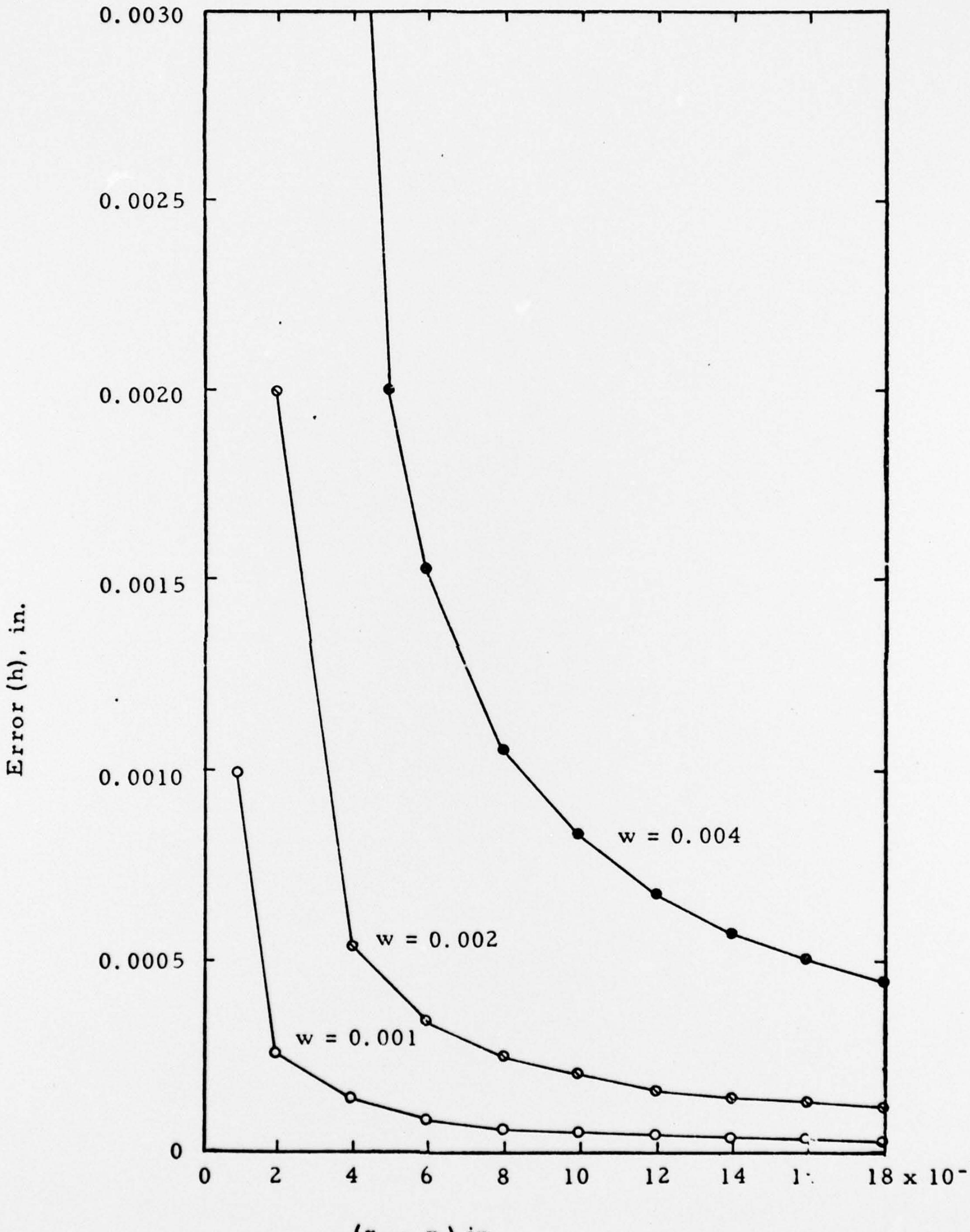


FIGURE B-4 ERROR DUE TO TIP DISPLACEMENT AND TIP RADIUS

ESA-11634:FMH:dms

DEC 23 1976

From: Director, Naval Weapons Engineering Support Activity
To: Commander, Naval Air Systems Command (AIR-340C)

Subj: Evaluation of the Spline Alignment Gage at the Naval Air Rework Facility (NARF), Norfolk, Virginia

Encl: (1) Spline Alignment Gage Evaluation Summary
(2) Illustration of the Spline Alignment Gage

1. In February 1976, the Naval Weapons Engineering Support Activity (ESA-116) requested NARF, Norfolk to perform an evaluation of the Spline Alignment Gage which was developed by Southwest Research Institute. The statement of work required NARF, Norfolk to utilize the spline alignment gage during routine shop operations and provide suggestions for design and operational improvements to the existing gage. NARF, Norfolk was also requested to provide an analysis of the operational and managerial resources which would be required to perform routine measurement of spline alignment and concentricity at a Naval Air Rework Facility.

2. Results and recommendations obtained from the six-month gage evaluation are provided in enclosure (1). The equipment description numbers refer to numbers used in figure 1 of enclosure (2).

3. NARF, Norfolk also provided a brief analysis on the feasibility of measuring spline alignment with the Bendix Sheffield Cordax machine which is currently installed in the Engine Overhaul Shop, not in the same building as the Gearbox Overhaul Shop. The major differences between the Cordax machine and the Spline Alignment Gage is that the Cordax machine is not portable, but requires a minimum of setup time. The Operations Analysis Division at NARF, Norfolk performed as comparative analysis between the long setup time required of the portable Spline Alignment Gage and the transportation and handling problems associated with the fixed Cordax machine. This analysis determined that the Cordax machine was unsuitable for routine spline alignment measurement due to:

a) loss of time in transportation

b) contamination of reworked ports from excessive handling

c) required modification of gearbox dollies for long-distance and rough-terrain transportation

Subj: Evaluation of the Spline Alignment Gage at the Naval Air Rework Facility (NAFR), Norfolk, Virginia

d) the requirement that the bore face of the gearbox spline pad be positioned perfectly horizontal in order to obtain accurate alignment readings on the Cordax machine.

4. The conclusions drawn by the evaluation of the Spline Alignment Gage at NARF, Norfolk are:

a) Due to technical complexity and excessive setup time, the Spline Alignment Gage is not suitable for routine operation at intermediate or depot-level maintenance facilities.

b) The Sheffield Cordax machines currently installed at Naval Air Rework Facilities are not suitable for spline alignment measurement.

5. The Naval Weapons Engineering Support Activity (ESA-116) and Naval Air Test Center (SY60) will continue efforts to develop a practical tool for measuring spline alignment and concentricity at the depot maintenance level.

T. E. MORTON
BY DIRECTION

Prepared by: F. M. Hall/X32069
Typed by: D. H. Sothen/20 December 1976

Spline Alignment Gage Evaluation Summary

The following paragraphs summarize the observations and recommendations made by personnel in the Operative Analysis, Engine Overhaul and Gearbox Overhaul Division of NARF, Norfolk during evaluation of the Spline Alignment Gage, March 1976 to August 1976.

1. The gage is limited in application because it will fit only specific pad sizes and spline configurations. The round gage base will fit only a 4.125-inch spline pad with specific positioning of studs. The indexing collar (28) on each gage limits the type spline which may be measured because the collar indexing grooves must correspond to the number and spacing of spline teeth. During the gage evaluation at NARF, Norfolk, an adapter plate was fabricated for the gage to fit a 10-inch size spline pad stud mounting.

2. During setup of the gage, the indexing finger (20) was difficult to hold away from the indexing collar (28) to allow rotation and centering of the probe tip (2).

3. The probe tip (2) was easily bent during routine operation and a harder material is recommended. The probe tip occasionally hung on the entrance to a female spline groove during insertion, causing deflection of the gage head (1). This problem was alleviated but not entirely eliminated, by increasing the angle of bend in the stylus tip.

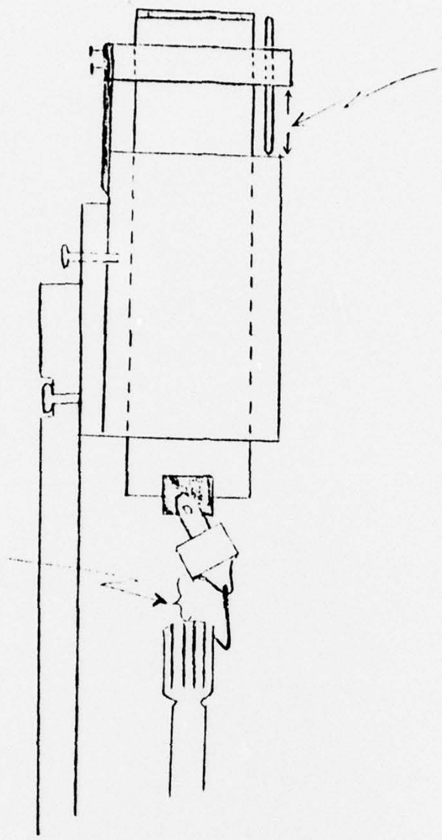
4. During the gage evaluation at NARF, Norfolk the brass thumb screws for positioning the lateral adjustment ring (17) were often tightened down with pliers during setup of the gage. Consequently, excessive wear occurred on the thumb screw heads. It is recommended that the thumb screws be replaced with brass wing-nut type bolts.

5. The weight of the gage increased the difficulty of setup. The average setup time for each pad during the evaluation at NARF, Norfolk was approximately 20-30 minutes for each pad.

6. When the gage must be placed in a vertical position on the gearbox, the traversing rod (23) must be held in an up position to take all "top" spline readings. The depth adjustment pin (26) will hold the rod in position for all "bottom" readings. Accuracy of "top" readings taken in a vertical position will be greatly increased if a practical means of holding the rod in "top" reading position can be devised.

7. As the traversing rod (23) is turned during measurement, the cable (24) is also twisted and will eventually become kinked and worn. During the NARF gage evaluation, the electrical connection on the cable at the far end of the traversing rod was broken due to twisting fatigue. A swivel cable connection at the end of the traversing rod would eliminate this problem.

8. This figure illustrates the two major problems of accessory spline measurement:



(a) "Top" readings must be taken while holding the traversing rod up.

(b) Readings can only be taken if clearance exists between the gage head and the spline.

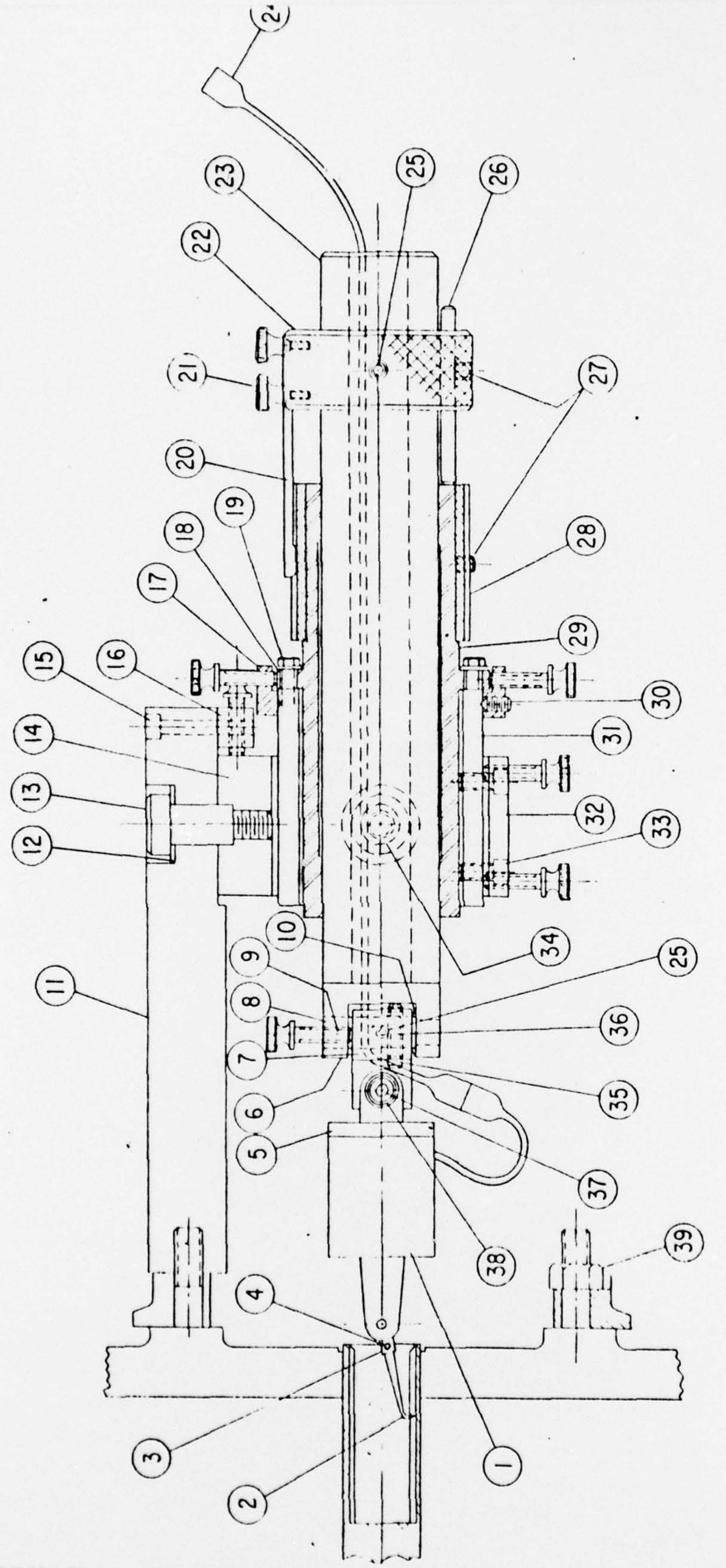


FIGURE 1. PARTS CALL OUT FOR GEARBOX SPLINE MISALIGNMENT GAGE

TABLE 1. PARTS LIST FOR GEARBOX AND ACCESSORY SPLINE MISALIGNMENT GAGES

Part No.	Description	Quantity
1	Gage head, Federal EHE - 1048	1
2	Probe tip	1
3	Probe positioner	1
4	Set screw, 2-56 x1/8	1
5	Conversion bracket	1
6	Mounting block	1
7	Positioning bracket	1
8	Pivot	1
9	Thumbscrew, 10-32 x 3/4	10
10	Belleville washer, Associated Spring Corp. B0750-028-S	2
11	Stand	1
12	Belleville washer, Associated Spring Corp. B1000-050	2
13	Shoulder screw, Jergens 41716	1
14	Pivoted angle	1
15	Socket head cap screw, 10-24 x 1-1/4	2
16	Stand bracket	1
17	Lateral adjustment ring	1
18	Washer	4
19	Hex bolt	4
20	Indexing finger	1

TABLE 1. PARTS LIST FOR GEARBOX AND ACCESSORY SPLINE MISALIGNMENT GAGES (Con't)

Part No.	Description	Quantity
21	Flat head screw, 4-40 x 1/4	2
22	Knob	1
23	Traversing rod	1
24	Cable	1
25	Set screw, 10-32 x 1/2	1
26	Depth adjusting pin	1
27	Set screw, 10-32 x 1/4	2
28	Indexing collar (one with 8 slots, one with 7 slots)	2
29	Traversing rod guide	2
30	Cone-point set screw, 10-32 x 3/8	1
31	Pivoted block	1
32	Alignment angle bracket	1
33	Socket head cap screw, 10-32 x 1/2	2
34	Shoulder screw, Jergens 41715	1
35	Set screw, 10-32 x 3/4	1
36	Spring plunger, Jergens 26903	1
37	Socket head cap screw, 1/4-28 x 7/8	1
38	Washer	1
39	Hex nut, 3/8-24	6
40	Threaded bolt, 3/8-24 (for accessory spline misalignment gage only)	6